Technological Change or Consistency? An Investigation of Faience Produced from the Middle to the New Kingdom at Abydos, Egypt.

Thesis submitted in accordance with the requirements of the University of Liverpool for the degree of Doctor in Philosophy by

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Abstract

For many years, it has been argued that faience underwent dramatic technological changes from the Middle Kingdom (2040–1640 BC) to the New Kingdom (1570–1070 BC) in Egypt. These technological developments are said to include changes in the sources of some of the key ingredients of faience production, including the silica, alkali, and colourant. However, the proposed technological changes are broad generalizations and, in the case of some faience bead assemblages, they appear to be non-existent. This thesis considers the reasons for the developments in faience production, and focuses on the changes themselves by analysing the chemical composition of faience beads from the Middle to the New Kingdom at the site of Abydos.

This research focuses on a sample of 151 beads, dating from the Middle Kingdom to the New Kingdom, which were found during John Garstang's early 20th Century excavations. All aspects of the beads were investigated in order to establish the production methods used – this was, in essence, reverse engineering of the beads. The investigation was accomplished with a combination of established and innovative analytical methods, some of which had not been tested on faience material before.

Scanning electron microscopy (SEM) was employed to determine changes in the microstructure, and led to an understanding of the glazing methods used in the production of the beads. Energy dispersive spectrometry (EDS) was used to test the chemical composition of the samples. Strontium isotope analysis was conducted to identify the raw material sources of the alkali used in the production of the beads. Electron backscatter diffraction (EBSD) was undertaken to determine the firing temperatures reached during production, and crystallography (CL) was undertaken to determine the silica source. Once these analyses were complete the archaeological samples were experimentally replicated and analysed. All of the results were then interrogated in order to prove, scientifically, whether or not Egyptian faience technology really underwent change from one period to the next.

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List of Abbreviations

BEI	Backscattered Electron Image
EDS	Energy Dispersive Spectroscopy
ICP-MS	Inductively Coupled Plasma Mass Spectrometry
KeV	Kiloelectron Volt
NIGL	Natural Environmental Research Council's Isotopic Geosciences Laboratory
SEI	Secondary Electron Image
SEM	Scanning Electron Microscopy
WDS	Wavelength Dispersive Spectroscopy
CL	Crystallography
EBSD	Electron Backscatter Diffraction

Oxide Elements

SiO_2	Silicon
Na_2O	Sodium
K_2O	Potassium
CaO	Calcium
MgO	Magnesium
Al_2O_3	Aluminium
Fe_2O_3	Iron
MnO_2	Manganese
Sb_2O_5	Antimony
CuO	Copper
CoO	Cobalt
BaO	Barium
TiO_2	Titanium
SnO_2	Tin
SrO	Strontium
Li_2O	Lithium
Rb_2O	Rubidium
V_2O_5	Vanadium
Cr_2O_3	Chromium
NiO	Nickel
Ag_2O	Silver
Bi_2O_3	Bismuth
P_2O_5	Phosphorus
Cl	Chlorine
SO_3	Sulphur
As_2O_3	Arsenic
PbO	Lead
ZnO	Zinc

Chapter 1: Introduction

1.1 Background to this Study

Egyptian faience is a non-clay, high-tech, glazed ceramic that consist of silica, alkali, and lime with a colourant such as copper to produce its signature blue shinny colour (Vandiver and Kingery 1987 b: 79). It is one of the world's oldest man-made materials and is found in Egypt, the Mediterranean, Near East, and Europe. The exact geographical origin of faience technology is unknown and its exact production methods remain unclear. Due to the fact that there is no written record from the Ancient Egyptians about why faience was made, how it was made, and with what raw materials, faience can only be understood through analytical methods. Since faience has existed for such a long period of time, questions have been asked by many archaeologists in an attempt to determine why faience is so prolific throughout Egypt's history and used in all levels of Egyptian society (Vandiver 1982, Kaczmarczyk and Hedges 1983, Patch 1998). One of the most frequent questions, is whether faience changed due to the introduction of new technology or various other influences? This research sets out to ask the same question in a diachronic case study of Abydos, a site that is one of the largest and most continually used cemeteries in Egypt.

Faience is made up of three main components: silica, soda, and lime. In typical faience, the silica (92% to 99%) forms the bulk of the body and is considered the network former. Alkali (soda) (0.5% to 3%) is added to cement the silica particles together and is the network modifier, which reduces the melting temperature of the silica (Kaczmarczyk and Hedges 1983: 20, Shortland 2000: 44). This can either be in the form of plant ash or natron. The addition of lime (1% to 5%) stabilises the network and stops the breaking down of the glassy material (glaze). In addition to the main components, there are trace elements, such as copper and cobalt, which are used as colourants. Other elements such as aluminium, titanium, magnesium, and potassium are possibly introduced unknowingly as impurities (Nicholson and Peltenburg 2000: 186).

Egyptian faience was produced for over 5,000 years, and the earliest examples date to c.4000 BC (Henderson 2000: 181, Shortland and Tite 2005: 31). Due to this long history of production, the technology changed over time. It has been stated by previous researchers in the field of vitrified materials, that Egyptian faience underwent dramatic technological changes between the Egyptian Middle Kingdom (c.2040–1640 BC) to the New Kingdom (c.1570–1070 BC) (Nicholson and

Peltenburg 2000). These technological changes were brought about by the development of other vitreous material industries, such as glass, and by the interactions and exchange of knowledge with Near Eastern manufacturers (Henderson 2000). The changes included alterations in the sources of some of the key components for faience production such as the silica (sand or quartz pebbles), alkali (plant ash or natron), and colourant (copper or cobalt) sources. However, these dramatic technological/compositional changes are not found within certain faience bead assemblages and may simply be the result of relatively unsupported generalisations that have gradually been transformed into a general consensus. It is possible that faience production did not change as rapidly/dramatically and was in fact very consistent in Egypt during this time period. This thesis will consider the reasons for the changes in faience, and will focus on the changes themselves by analysing the chemical compositions of faience beads from the Middle to the New Kingdom.

The Middle and New Kingdom were chosen for this research due to previous conclusions that were drawn regarding faience production during these periods. The Middle Kingdom is considered to have been a period of expansion for faience working, with the manufacturing of faience accelerating, and faience working itself becoming more prestigious (Nicholson and Peltenburg 2000: 182). The New Kingdom witnessed the introduction of new colours and improvements in the quality of work being produced. During a pilot study (Hammerle 2008) it was found that faience beads from the two periods were very similar in composition and production methods, and that overall the technological changes were not evident. However, as there were only eleven beads analysed in the pilot study, a full PhD programme of research was undertaken to expand the number of samples analysed and to increase the statistical data in order to produce firmer conclusions. The conclusions of this past research left some questions open for further analysis: was the faience from the New Kingdom an improvement on faience as a material or just an expansion of some technical aspects? Is the New Kingdom the zenith of Egyptian faience, due to the increase of production and the quality being produced? Over this period of 970 years did faience technology really change significantly, and if so how does one quantify this process of change?

1.2 Research Statement

This research focuses on a sample of 151 beads covering the Middle Kingdom, Second Intermediate Period, and the New Kingdom, deriving from the excavations of John Garstang at Abydos, Egypt in the early twentieth century. The

samples are from the Garstang Museum (University of Liverpool), the Manchester Museum (University of Manchester), and the Bolton Museum (see Chapter 3 below). These beads are used to attempt to specifically determine how faience technology and chemical composition changed from the Middle to the New Kingdom. The research addresses questions related to the specific sources of the silica, alkali, and colourants utilised. Every aspect of the faience beads is investigated, using a number of different and complementary analytical methods including: scanning electron microscopy coupled with an energy dispersive spectrometer (SEM-EDS), crystallography (CL), electron backscatter diffraction (EBSD), and strontium isotope analysis (see Chapter 5-7). Results from these analyses are interrogated in order to better understand whether Egyptian faience technology changed over time (Chapters 8 and 9).

1.3 Objectives

As noted above, the current research builds on a pilot project conducted in 2008 (Hammerle 2008), expanding it with unique approaches. The objectives of the pilot project are incorporated into the current research and broadened. The objectives that were established for this thesis include developing a methodology for characterising the differences in faience technology through the analysis of compositional differences using SEM-EDS. A further objective was to establish a typology, or a system of classification for Egyptian faience, and to determine whether or not the raw materials used in faience manufacturing changed from one period to the next. This is achieved by using EBSD, CL, and the chemical analysis data, thus aiding the overall goal of the research by providing the information and the results required to compare the Middle Kingdom faience to the New Kingdom faience, and to quantify the technological changes that occurred.

1.4 Aims

The current project has three main research aims and two very general aims. The first aim is to expand the use of analytical methods in Egyptological studies. This will enable a deeper understanding of past societies through its material culture, which in turn will inform us about the individuals who created and used faience. The second and most ambitious aim is to create a working model, which will enable other archaeologists to identify different production features of faience beads, using a series of analytical methods and incorporating science-based archaeology. Thirdly, the most straightforward aim of this research is to investigate whether or not faience technology changed from the Middle to the New Kingdom.

There are two other very general aims of this research, the first of which is linked with the three stated above, and is to expand on our understanding of the technical aspects of faience and their implications. The second is to expand on the way archaeologists utilise beads to understand past cultures. This secondary goal is aimed at raising the profile of beads as an artefact type. Their greater archaeological and scientific value will be determined by utilising analytical methods to gain information on how they were produced, including the raw materials and forming methods utilised. However, another aspect, which will also be addressed, is the reason for their production, whether for utilitarian or ritual purposes, and why they were eventually buried within a mortuary assemblage.

1.5 Questions

This project established average compositional groups within a very large body of unique data never previously accumulated. As these groups become apparent there are a considerable number of questions that this research sets out to answer. A few of the questions are listed below:

i) Did the chemical composition change? If so, how?

ii) What are the compositional variations from the Middle to the New Kingdom in regards to faience?

iii) Did production methods, such as glazing and shaping, change from one period to the next, and was one favoured more than another?

iv) Was one period's faience necessarily better than the other? If so, why/how and how can the distinction be made?

v) What characteristics are ideal/valued by those who made the artefact? And how can we tell?

vi) What caused the changes in technology overall? Was it importation, a change in raw material, or was it due to the development of the glass industry?

vii) What are the potential origins of the raw materials?

1.6 Methodology

This research aims to develop a protocol for studying faience using a multitude of analytical methods. The main method that was utilised is scanning electron microscopy (SEM) and it was chosen because energy dispersive spectroscopy (EDS), electron backscatter diffraction (EBSD), and crystallography (CL) can all be accomplished with it. However, in this case the analysis was completed using two different SEM machines, one for SEM-EDS and another for

EBSD and CL. In using SEM all the samples were prepared in the same way. The beads were cut in half in order to expose the core material. One half of the bead was then set in resin, then ground and polished for analysis. The other half of the bead will remain in the museum with the rest of the assemblage. All of the analysis and sample preparation was undertaken at the University of Liverpool in the Department of Archaeology, Classics, and Egyptology, except for EBSD and CL, which are only available in the Earth and Ocean Science Department.

SEM-EDS was chosen for this research in order to record the micro-topography of the faience beads. A full profile (edge to edge) of each bead was taken. This image helped to determine the glazing method that was used in the production of the beads. EDS will aid in determining the chemical composition of the interstitial glass layers, in order to determine what colourant, silica, and alkali was being used in the production of the beads.

EBSD is a new method to archaeology and was used to determine the firing temperatures reached during the production of these faience beads. Additionally, crystallography (CL) will be employed to determine the exact nature of the silica crystals that comprise 92% to 99% of the core material of faience. This interpretation will be based on the structure of the silica crystals, which provide information about their homogeneity and relate this to the purity of the raw material source. This is the first time these methods have been applied to faience and is a collaborative work with Dr Elisabetta Mariani of the University of Liverpool Earth and Ocean Science Department.

Strontium isotope analysis was also undertaken to aid in determining the alkali source utilised in the production of faience materials. This work was carried out with the aid of a grant from the Natural Environmental Research Council's Isotopic Geosciences Laboratory (NIGL). This is the first time strontium isotope analysis was conducted on faience materials.

1.7 Terminology

It is important to discuss the terminology used in this thesis in order to avoid confusion and to provide consistency with terms that are often disputed. The term faience itself is considered to be a misnomer, as it is originally a French word derived from Faenza, an Italian town known for its majolica or tin glazed, decorated, earthenware (Nicholson 2009: 1). The major differences between majolica and the material that researchers now consider to be faience are that faience is not made from clay, nor is it glazed with tin. However, it is similar in appearance. Over time, faience started to be used with reference to objects with Egyptian origins, being

called Egyptian faience. This created another problem, since faience is found in cultures other than Egypt, as far afield as Europe and China. Eventually the adjective 'Egyptian' was dropped, as it could be mistakenly taken to imply the faience objects' origins. The term faience was modified again, and many researchers began to specify what they meant by faience in order to avoid any confusion, or, in some cases, they even used other terms instead, such as 'glazed composition' (Nicholson 1993: 16, Wilkinson 1971).

Ultimately, however, the term faience is now generally accepted in the archaeological science community, and will be employed throughout this research. In this project, faience will be used to describe a glazed non-clay ceramic with a ground quartz core, and does not imply anything about the possible place of manufacture of the object. The material termed faience in this research is considered to be the first high-tech non-clay ceramic (Vandiver and Kingery 1987 a). It is the earliest synthetic material produced by man. Faience is made of crushed quartz or sand, with either natron or plant ash added as the alkali, and lime added either intentionally or by accident. A colourant such as copper is often used to produce its common blue-green colour, but other elements have been utilised to create a range of colours (Nicholson 1998: 50).

In Egypt there are several vitreous material industries that often get confused with each other, due to complications in terminology. These include glazed steatite, faience, and Egyptian blue and green frits. Frit is another term that is commonly seen with reference to faience. It has the same compositional elements as faience: silica, lime and soda, but in very different quantities. In fact the only differences between glass, faience, and frit are the different amounts of alkali utilised and their firing temperatures. Frit is not heated high enough to be able to flow like glass (Kaczmarczyk and Lahanier 1985: 97). It should also be noted that early Egyptologists have used the term frit to refer to artefacts that would now be considered to fall within the category of faience.

Many current researchers analysing faience have begun to substitute 'interstitial' for 'interparticle', when referring to the glassy vitreous material viewed within the core of the faience material, using SEM (Tite *et al.* 2007: 1571, Rehren 2008: 1347). In this research the current trend is followed, and interparticle is used to refer to the glass bonding the individual silica grains together.

EDS is used here as the acronym for energy dispersive spectrometry, rather than EDX (energy dispersive x-ray) or EDA (energy dispersive analysis). All of the acronyms have been used in past research and are easily interchangeable. In this

research EDS was chosen because the analysis is done with the aid of a spectrometer.

The use of the term natron to refer to the sodium-based component of faience is another term under great debate. Strictly speaking, natron is a naturally occurring mix of sodium carbonate decahydrate, whereas the dominant carbonate in the deposits from Wadi Natrun used for faience manufacturing is sodium carbonate bicarbonate, which is chemically known as *trona* (Shortland *et al.* 2006: 521). However, Wadi Natrun has eight lakes and there are minor fluctuations in the exact composition of the deposits of each of these lakes. Therefore the deposits can be either natron, *trona* or a mixture, and to be consistent with past research this thesis will use 'natron' when referring to the alkali sources.

1.8 Overview of Chapters

This thesis consists of nine chapters. Each chapter will be discussed in brief here to give an overview of the research plan. The first three chapters present background information; Chapter 4 addresses the samples themselves, and Chapters 5 through 7 present the different analytical methods utilised in this research. Chapter 8 discuss the results, and Chapter 9 forms the conclusion.

Chapter 2 presents the background of faience, from its origins, to its importance in Egypt. As mentioned there are several types of faience, which are all discussed in depth in this chapter. There is a section on how faience technology changed over time introducing research ranging from the Predynastic to the Third Intermediate Period. Raw materials and production methods are discussed in full, including glazing methods, forming, decorating, and firing. The second section of this chapter presents a background discussion on beads, including their origins and uses. The terminology and classification systems currently used for bead research are outlined, along with theories on how beads tend to be incorporated into the archaeological record. The importance of beads to ancient cultures, specifically Egypt, is discussed, along with the production methods of the beads.

Chapter 3 introduces the site of Abydos, where all the beads analysed in this thesis were excavated by John Garstang in the early twentieth century, first working under Petrie (Garstang 1901), and then in his own right (Snape 1986). The excavations are discussed here, along with the sources of the current samples: the Garstang Museum, Manchester Museum, and Bolton Museum. The tombs that the beads came from are considered in detail, including the other artefact types within the tomb assemblage, the bead assemblage itself, and how the material was dated to its specific time period.

Chapter 4 presents the samples themselves and explains how they were selected from among the other beads within the same assemblages. This includes the statistical information and the initial inspection of each bead sample with regard to its weight, drawings, hardness, and colour. The long process of sample preparation is then explained, for it is essential for many of the analytical methods discussed in this research.

Chapter 5 presents a discussion on the main set of analytical methods used for this research: SEM-EDS. This section will include justification as to why this set of methods was chosen, how the analysis was conducted, and how the results have been interpreted.

Chapter 6 discusses the use of strontium isotope studies on faience material. This type of analysis has never been conducted on faience before. A background on how this method has been applied to ancient glass is presented, along with a comparison of the results for glass to interpret the implications for faience.

Chapter 7 covers all the experimental archaeology used in this research, including the production of faience beads and the firing experiments. These replication experiments investigate the composition of faience and will incorporate the use of EBSD and CL analysis. The results are then presented, along with their implications for the archaeological community.

Chapter 8 presents the overall results of the various different analyses, and the results for each time period are compared in order to draw conclusions about the potential changes in faience over time. Chapter 8 uses statistical analysis of the data, in order to further discuss the comparisons made in previous chapters. These analyses provide the ultimate understandings required for the conclusions presented in Chapter 9.

Chapter 2

Background: Faience and Beads of Egypt

2.1 Faience

A description of what the material faience is, in the strictest sense of the term, was given in the introduction (Chapter 1 above). This chapter addresses the material with further consideration and in greater depth. However, it should be borne in mind that this material has caused considerable confusion in the past, and it is not as straightforward as one would hope (Robinson *et al.* 2004: 79).

To begin with, faience was first assigned the descriptive term 'high-tech ceramic' by Vandiver and Kingery (1987 a) to stress its status as an artificial medium. It is the first synthetic material made by humans, and is considered to have led to the invention of glass (Peltenburg 1987: 18). Because of this, faience is considered to be one of 'the early vitreous material industries' of the Near East and Egypt. These industries also include glassy faience (in between glass and faience), glass, and frit. All of these materials have the same basic chemical composition of silica, soda, lime, and varying colourants such as copper oxide (Tite 1987: 21). Because of faience's similarity with glass, there are numerous references to both materials in relation to each other. See Section 2.1.2.3 below for a discussion on the possibility that the ancient craftsmen might not have made the same distinction between the two materials that we make now.

Faience is a glazed, 'contrived', non-clay ceramic material (Vandiver and Kingery 1987 b: 79) and can only be characterised by analytical methods (Tite and Bimson 1987: 81). There are three distinct layers in faience objects: the quartz-dominant core/body, the glaze, and the interparticle glass, which cements the core and glaze together (Hodges 2000: 51, Tite 1987: 21, Shortland 2000: 2). The typical body of a faience object has a basic compositional range of 92-99% silica, 1-5% calcium, 0.5-3% sodium, and minor quantities of aluminium, titanium, magnesium, potassium, and copper (Vandiver 1982: 167). Copper is added as a colourant to make the faience blue. Faience can also be found in shades of green, red, black, orange, and yellow.

2.1.1 Origins and Dispersion

As mentioned in Chapter 1, one of the most difficult issues to deal with in vitrified materials studies is terminology, and the fact that many archaeologists, art

historians, ethnographers, historians, material scientists, and Egyptologists use different names to describe the same material. Faience has been referred to as a tin-glazed earthenware (which is why it has the name 'faience' in the first place, as stated in Section 1.7) (Lucas and Harris 1962: 156). It has also been referred to as porcelain, glazed pottery, glazed composite, and various other names (Andrews 1990: 57). Even frit has been used to describe faience, which is inaccurate, as frit is a different technology, i.e. either glass-making frit, or the non-glazed object variety. All of these misnomers and various descriptions for the material referred to as faience attempted to fill a gap in the English language. There is no word for faience in English, and due to the passage of time since 'faience' was introduced to English-speaking academic communities, it is too late to consider renaming it now. Because of the extensive vocabulary utilised for faience, it is challenging for vitreous material researchers to study the origins of the material.

The earliest researchers in the field came from many different countries. The process of researching museum catalogues, excavation reports, and field notebooks is therefore fraught with problems, and one must scrutinise any possible artefact or catalogue that could be relevant to one's research. Due to difficulties with the literature and terminology, there is a serious lack of archaeological evidence regarding the origins of faience. It is now almost impossible to determine if faience was created first in Western Asia or Egypt (Stone and Thomas 1956: 138). Only new and extensive excavations will help to solve this riddle. Until then, it is necessary to work with the information provided by previous research on the origins of faience, which will be presented in the following section.

Faience is considered to be the oldest and most continuously produced vitreous material in history (from the fourth millennium BC to the 14th Century in Egypt) and it is both abundant and important throughout Egypt, the Near East, Europe, and Asia (Henderson 2000: 181, Tite 1972: 352, Tite and Bimson 1987: 87, Tite *et al.* 1983: 17, Rehren 2008: 1347, Shortland 2000: 2, Tite and Bimson 1986: 69). In a recent article, Matin and Matin (2012: 763-764) stated that the use and production of faience continues to this day in Qom, Iran, using the same methods as those employed in ancient cultures.

The origin of faience has been narrowed down to either the Near East (Northern Mesopotamia) or Egypt, although, as stated above, the records leave something to be desired (Foster and Kaczmarczyk 1982: 177, Tite 1972: 209, Tite and Shortland 2008: 209). This lack of accuracy coupled with the difference in chronologies and environments (causing weathering), complicates the process of determining the oldest faience material ever found (Moorey 1994: 166-168).

Stone and Thomas (1956: 40) concluded that the faience industry originated in Western Asia, based on the typological evidence presented in their article. Subsequent research maintains a strong argument for the invention of faience in northern Mesopotamia. This concurs with the earliest examples of faience found in Mesopotamia, which date to the Ubaid period (c.5400-4300 BC (Paynter 2009: 93). Faience beads were also found at Brak, Mesopotamia, and were dated by Mallowan to c.3200 BC (Aspinall *et al.* 1972: 27). Even though Egypt might not be able to claim the invention of faience, they were accomplished in its production and innovative with the material (Noble 1969: 435).

Once faience was invented, it did not take long to spread to other regions. The finished artefacts and recipes were traded over vast distances. It is possible that local production sites started to appear once the material became familiar and the desire for it increased. The raw materials for faience are common and found in most landscapes around the Mediterranean (McGovern *et al.* 1993: 22). Once the production methods started to spread via craftsmen and technological transfer of knowledge, it would have been possible for local industries to flourish (Panngiotaki *et al.* 2004: 149). Some of these locations and production centres will be discussed here.

Beth Shan (in Jordan) was a New Kingdom Egyptian camp (McGovern *et al.* 1993: 1). Faience found at this site was probably produced locally, as the inhabitants of Beth Shan possessed the raw materials to make faience, and were already producing Syro-Palestinian glass at the time. This glass, and probably the faience, was produced using local metal ores. The colourants procured from this area could have led to the technological changes in faience manufacturing during the New Kingdom in Egypt, according to McGovern *et al.* (1993: 1-2).

In the Aegean, faience is found from the third millennium BC onwards, right across the region, from Crete to Thessaloniki, in the form of beads and vessels. According to Tite *et al.* (2009: 370) faience found on Minoan Crete could have been made locally. Panngiotaki *et al.* (2004: 148) found that Aegean faience and Egyptian blue frit were being produced locally, with resources found in Minoan Crete, based on the iconography, and analysis of artefacts.

In Europe, faience has been found in many different countries including Poland and the British Isles. Both countries produced their own faience, though on a much smaller scale than the Mediterranean and Egypt. In The British Isles over 300 faience pendants and beads have been found at over 120 different sites (Sheridan and Shortland 2004: 263). Robinson *et al.* (2004: 111) came to the conclusion, after

extensive analysis at sites in Poland, that faience was being produced locally in central Europe during the Bronze Age.

Stone and Thomas (1956: 37) concluded that faience was produced in Egypt and then dispersed to areas such as the British Isles. Most of their theory was based on the typology of the beads. Newton *et al.* (1970: 199) was inclined to agree with Stone and Thomas, based on the fact that the 'segmented' beads of Europe were similar to those from Egypt. However, further analysis might prove a local production centre.

2.1.2 Technology Over Time

The origins of faience technology, although they cannot be tied to a geographical region, can be linked almost directly to what was a pre-existing technology. The first material to be glazed was steatite (Nicholson and Peltenburg 2000: 177). This would have been a piece of steatite (or quartz) pebble covered with malachite or copper and a little natron, and heated in a fire to produce a glazed blue-green stone that could be drilled for jewellery (Noble 1969: 437). This technology may have developed purely by accident, since no other similar technology existed before this. The earliest glazed steatite can be dated to the Badarian Civilisation in the Predynastic Period (fifth millennium BC) in Egypt, and are mostly beads (Lucas and Harris 1962: 155, Stone and Thomas 1956: 44). Faience came shortly after, during the Predynastic Period, and continued to be produced until the 14th century AD (Table 2.1) (Lucas and Harris 1962: 155, Tite and Shortland 2008: 23).

Faience and glazed steatite were used alongside each other until the Late Period. Many researchers have asked why two different technologies would be used simultaneously to get the same results (Tite *et al.* 2002: 587). It is possible that faience was easier to use and make. It would take longer to work a stone into a bead than to form a bead from faience, and the faience glaze was more lustrous (Tite *et al.* 2002: 587). The following table illustrates the different processes involved in the production of faience over time, specifically the methods for forming the faience artefact and the glazing method. There are three glazing methods: application, cementation, and efflorescence (discussed in more detain in Section 2.1.7.2). The first method, application, is achieved by painting the glaze on as a slurry or dipping the faience body in the slurry. Cementation glazing occurs when the faience body is buried inside the glazing powder and the glaze liquefies during the firing process (Vandiver 1982: 170). Lastly, efflorescence glazing occurs when the faience body and glaze material are mixed together and then left to dry, so that

the glazing salts then effloresce to the surface of the object and once fired liquefy to form the glaze.

Period	Body Manufacture	Glazing Process	Factory Evidence
Predynastic	Modelling a core for grinding Surface grinding Free-form modelling (rare)	Application (?) Cementation (?) Efflorescence (?)	None known
Early Dynastic	Modelling Surface grinding	Efflorescence	None known
Old Kingdom	Painting with slurry Layering (rare)	Efflorescence	Abydos
First Intermediate Period	Core forming (rare) Marbleising (rare) Moulding (?)	Efflorescence	Abydos
Middle Kingdom	Modelling on a form (Patrix)	Efflorescence Cementation	Lisht Kerma (Sudan)
Second Intermediate Period	Core forming Marbleising Layering Painting with coloured quartz slurry Incising Inlaying Resisting Painting with pigment wash	Application	None known
New Kingdom	Moulding on a form Pressing into open face moulds Layering Incising Inlaying with quartz slurry Painting with pigment wash Throwing	Efflorescence Application Addition of finely powdered glass to body (??) and/or glaze to extend colour range	Malkata Amarna Qantir Lisht
Post New Kingdom	As New Kingdom but with greater use of throwing (?)	Application Efflorescence	Memphis Naukratis Buto

Table 2.1: Egyptian faience technology overtime (adapted from Nicholson and Peltenburg 2000: 188).

2.1.2.1 PREDYNASTIC AND OLD KINGDOM

The earliest faience objects were beads and amulets of a blue-green colour (Patch 1998: 32). These beads are dated to the Predynastic Amratian phase (Naqada 1, c.4000-3500 BC; Stone and Thomas 1956: 40, Moorey 1994: 168). During this time, Egypt was becoming more of an urban civilization, social

stratification was developing, and craft specialization was beginning to be exploited by the new elite (Bianchi 1998: 22, Friedman 1998: 17). Throughout this period, faience making was variable and experimental, which would be expected for a new technology (Vandiver 1982: 170).

From the Predynastic to the Old Kingdom, faience objects started increasing in size, from small beads to larger pieces that required luting. The most common objects were beads and amulets for personal adornment, but other artefacts, such as tiles, small vessels and figurines, increased in quantity during this time (Aspinall *et al.* 1972: 27, Vandiver 1982: 171). No specific type of artefact was produced exclusively in faience (Patch 1998: 32). However, faience was often used to copy other types of materials such as coiled baskets, clay and stone (Friedman 1998: 16). Vast numbers of these objects were used for religious purposes, and possibly only funerary purposes, rather than as items for daily use (Friedman 1998: 16).

In the Old Kingdom, faience production increased in quantity from the Predynastic, and was even, at least in one case, mass-produced. Some 36,000 small faience tiles were found in Djoser's (3rd Dynasty) Step Pyramid at Saqqara (Patch 1998: 32). These tiles were suspended from the walls within the Pyramid. The tiles were made by a 'controlled forming' method, which maintained an average thickness and length, although the width of the tiles varied. This technique involved rolling the faience material between two parallel sticks (Nicholson and Peltenburg 2000: 179). The tiles were then glazed by efflorescence, which was the preferred/common glazing method during the Old Kingdom (Vandiver 1982: 175). These tiles were once considered to be the pinnacle of Old Kingdom faience production, until excavations at Abusir unearthed the pyramid of the 5th Dynasty ruler Neferefra (Nicholson and Peltenburg 2000: 179). The excavation found faience that was incised and decorated with gold leaf. This material is finer than any found before, and displays a level of skill not witnessed before this time (Nicholson and Peltenburg 2000: 179).

2.1.2.2 MIDDLE KINGDOM

Faience technology did not change from the Old Kingdom to the First Intermediate Period. However, during the Middle Kingdom faience working accelerated and became the most experimental since the Predynastic (Nicholson 1993: 23, Nicholson and Peltenburg 2000: 181). The craftsmen were more skilled, and the execution of the techniques more exquisite, than had been seen before (Vandiver 1982: 175). The Middle Kingdom was a long and stable phase in Egyptian history, after all the disorder of the First Intermediate Period. The growth of

a middle class led to an increase in private tombs, and faience objects became more common (Bard 1999: 95). It has even been suggested that during this time, faience was not used on a daily basis, but could have been 'reserved for burials' (Patch 1998:32).

Changes in faience technology included an increase in the size of objects, such as statuettes, and the more frequent use of decoration in the form of black outlines (Patch 1998: 32). Faience, during this time, can be characterized by the body forming techniques utilised in its production, such as forming over a core (usually a ball of straw), which is a form of modelling. One of the most distinctive objects from the Middle Kingdom is the faience hippopotamus, which became very popular during this time, and was probably formed using the method mentioned above (Nicholson and Peltenburg 2000: 181).

Cementation glazing was used for the first time in the Middle Kingdom and therefore all three glazing methods were utilised (Vandiver 1982: 175, Nicholson 1993: 23). All three glazing methods produced during this period was better than any before- it was harder, longer lasting, and brighter (glassier) (Nicholson 1993: 23). This improvement was due to the addition of a fine-particle quartz layer over the core material, which vitrified completely during firing (Nicholson and Peltenburg 2000: 18, Nicholson 1998: 58). This increase in production methods and strategies essentially defined the faience technology of the Middle Kingdom and Second Intermediate Periods.

The few archaeological remains of this time come from excavations carried out comparatively recently. During the excavation of Lisht (from 1920-21) a rich burial was discovered, which belonged to Debeni (13th Dynasty), an 'overseer of faience workers'. This is the first known burial of such a person, and in fact one of the very few references to faience ever found in Egypt (Nicholson 1993: 23). One of the most important excavated sites for faience production is the earliest and almost complete workshop at Abydos, found by a joint excavation of the University of Pennsylvania and Yale University Institute of Fine Arts (on going since 1966; Bard 1999: 96). This workshop area is not associated with a house and is considered to be a factory site, with open firing evidence for faience, and dates from the Old Kingdom to the Middle Kingdom (Nicholson and Peltenburg 2000: 180-181).

During the late Middle Kingdom and going into the Second Intermediate Period, faience began to change (Vandiver 1998: 122). This could have been due to influences from outside of Egypt, such as the Hyksos, who took over the Delta area during the late Second Intermediate Period. During this time the Hyksos set up extensive trade networks in the Eastern Mediterranean, and the importation and

exportation of objects probably increased. Also during this time, mortuary cults seem to have been suspended from about the 13th Dynasty until the New Kingdom (Bard 1999: 54), which may have affected the faience industry and demand for the material for mortuary purposes.

2.1.2.3 NEW KINGDOM

The New Kingdom restored native Egyptian rule with the reign of Ahmose (1550-1525 BC), political stability returned, and various aspects of traditional Egyptian culture came back into use (Bard 1999: 57). It was also at this time, however, that glass technology was introduced to the repertoire of the vitreous material craftsmen in Egypt. It has been suggested that glass and faience were produced in the same workshops, and that Egyptians thought of the materials as the same, or at least that Egyptians recognised that they required the same raw materials (Nicholson 1998: 51). With this new technology came a whole new colour palette, especially polychrome, cobalt blue, and the introduction of other oxides as pigments (Boyce 1989: 161, Tite and Shortland 2003: 285, Vandiver 1998: 122-123, and Vandiver 1982: 176).

Faience is considered to have reached its peak of innovation and accomplishment during the New Kingdom, when it built upon the achievements of previous periods (Boyce 1989: 160, Nicholson and Peltenburg 2000: 182, Shortland 2000: 1). These innovations included the increase in colour options and combinations of new materials. Another innovation was the expansion of moulding with open face moulds, which led to the mass production of intricate identical pieces of a consistent and often very large size (Patch 1998: 32, Boyce 1989: 160, Nicholson 1998: 60). In addition, a larger variety of artefacts were produced, such as architectural tiles, intricate inlays, game pieces, vessels, and finger rings (Patch 1998: 32, Vandiver 1998: 122).

Finger rings were mass-produced, and those bearing a king's name were probably distributed during major royal festivals (Boyce 1989: 160). The faience finger rings were made possible by a better body material and a more vitrified structure that held up well during moulding and drying (Nicholson 1998: 60). Thousands of such moulds were found all over Amarna by Petrie (1900), which indicates that these methods were extensively used.

2.1.2.4 THIRD INTERMEDIATE PERIOD AND BEYOND

After the New Kingdom, and during the Third Intermediate Period, faience technology became stagnant. By the Late Period, faience had spread to most of the

known world, including most of Europe, the Mediterranean, India, and possibly even China. Due to the existence of the technology for such a long period of time, and the dispersion of the production methods, which led to local copies being made, it is difficult to differentiate between locally produced and imported material in Egypt (Nicholson and Peltenburg 2000: 184). However, the later material changed considerably.

The sites of Kom Helul and Kom Qalama in Memphis date to the Ptolemaic and Roman Periods. They were originally excavated by Petrie in 1909 and 1911, and re-examined by Nicholson (2002: 90). These sites are helping to expand the basic understanding of Egyptian vitreous material technology for this period. Ptolemaic and Roman faience was stylistically and technologically different from the faience produced in earlier periods (Mao 2000: 185, Shortland and Tite 2005: 31). During this time, clay was added to faience paste in order to improve its workability (Shortland and Tite 2005: 31). With this addition the craftsmen were able to create wheel-thrown and high relief vessels (Shortland and Tite 2005: 31). Also, it seems that lead was commonly used as a colourant, which gave a distinctive pale greenish colour to faience (Mao 2000: 200).

2.1.3 Importance to Egypt

As stated earlier, faience can be a confusing material. There are many debates regarding faience and what it meant to the Egyptian people. Was it a cheap substitute for gemstones, or did it have a significance of its own? Were different values assigned to faience, based on its colour? Could its ancient meaning have outweighed any modern view of its worth? What is known is that all sexes, ages, and social classes in Egypt used faience. These issues will be addressed in the following section, in order to determine the significance and importance of faience to Egypt.

There are several different theories, including the idea that the technology was developed in order to fill a demand for blue stones, replicating the sky and water (Nicholson 2009: 1). To an extent this may be true. However, we may never know for certain why the material was originally created. One thing is certain – faience would have been very inexpensive to make, as most or all of the raw materials could be locally sourced throughout the Mediterranean, and it was easily mass-produced (Patch 1998: 33). However, the craftsmen still required knowledge and skill for its manufacturing and production could have been time consuming.

It is often suggested that faience is an inexpensive substitute for gemstones, specifically the blue ones, which had to be imported from great distances (Tite and

Bimson 1987: 81). Lapis lazuli would have been imported from Afghanistan (the only known source in antiquity) and turquoise could have been imported from the Sinai (Friedman 1998: 15, Tite and Shortland 2008: 57). However, faience might not necessarily be a replacement for the stones mentioned, for a number of reasons. This is partly based on the fact that faience is found more frequently in royal tombs than any other individual tombs during the New Kingdom, when faience was mass-produced and available to all (Nicholson 2007: 133, Tite and Shortland 2008: 57). Its use in royal tombs indicates that faience might have had some funerary function that could only be satisfied by this material. It is also supported by the fact that there are some artefacts in which faience was incorporated with gold and gemstones (Bianchi 1998: 24). If the Egyptians valued faience as we do its modern equivalent, plastic (as it is readily available, mass-produced, and an alternative to other materials), they would not have placed it alongside gold in a bracelet, since it would have diminished its value. This shows that modern ideas of 'economic hierarchy' for raw materials cannot be applied to this ancient material (Bianchi 1998: 24). Faience was of value to the Egyptians for its own merits, and for its associations with other materials. As Paynter and Tite (2001: 252) state so eloquently, "the processes for producing an artefact must be interpreted in the context of the culture in which the artefact was created, and not in the context of the culture in which it is being studied". Faience may be inexpensive to make, but that fact does not in itself reduce its significance to the people of Egypt.

2.1.3.1 FAIENCE FOR EVERYONE

Faience is found in the homes and tombs of all socio-economic levels in Egypt, which could be related to its mass production, and therefore its ready availability to all (Friedman 1998: 15, Patch 1998: 41). However, faience is more commonly found in royal tombs than in tombs of any other social level, and was used to make a variety of artefacts. Thus it appears to have been specifically selected as the material of choice, based on its assigned significance to Egypt. As Patch (1998: 42) puts it, "apparently faience was not a material that the poorer members of society were forced to use, but rather was chosen for certain funerary and cultic items". If faience were just a substitute for rare and more expensive materials, the wealthy would presumably not have used it to the extent that they did.

Faience was not a royal or elite monopoly as glass was when it first appeared in Egypt (Shortland *et al.* 2001: 151). However, there were probably two different types of workshop - the deluxe (possibly state-run or elite workshops) and smaller workshops for private individuals. The so-called 'deluxe' objects would have

been produced at the first type of workshop by expert craftsmen for a discriminating clientele (Bianchi 1998: 22). Faience from the smaller workshops would have been distributed through private exchanges (Shortland *et al.* 2001: 156).

Faience needs to be considered technologically rather than economically. The craftsmen were very skilled, and many different types of artefacts were made with faience, according to its cultural significance (Paynter and Tite 2001: 251). Faience was utilised to make anything from the smallest beads to the largest bowls and *was*-sceptres (over 2 metres high). A small list of items includes, but is not limited to: *scarabs*, tiles, animal figurines, plants, cosmetic bowls, *shawabti*, architectural inlays, and vessels (Lucas and Harris 1962: 156). However, about half of the faience found at sites such as Amarna, was made into jewellery and personal adornment, including many beads, rings, and bracelets (Shortland *et al.* 2001: 155).

2.1.3.2 TEXTUAL EVIDENCE

Textual evidence for faience is very limited (Aspinall *et al.* 1972: 28, Shaw 2004: 12). There are no known recipes or concrete depictions of faience being made, let alone anything describing its significance to the people of Egypt. This is rather odd considering this is a culture that normally depicted everything from daily life to major events. There are two theories that may answer this conundrum, the first of which is that Egyptians did not value the material, and therefore did not bother to record it, because it was too mundane (Freestone 2008, Gordon 1993: 75). Alternatively, Egyptians may have valued it so much that the recipes and technology were kept secret, and any depiction of the process was prohibited. This would mean that faience had, "inherently magical and religious significance, accounting for its absence from the visual record" (Friedman 1998: 17). A third theory will be introduced in Chapter 7, which suggests that the Egyptians might not have even known what the recipe was, in our modern understanding of it.

The Egyptian word for faience is *tjehenet* (meaning brilliant or scintillating), which highlights its lustrous quality (Friedman 1998: 15). Another word for faience, which dates to the New Kingdom, and is used less frequently, is *khesbed* (Nicholson 1998: 55). The same word is used for lapis lazuli, turquoise, and sometimes glass, and links the materials together (Nicholson 1993: 11, Nicholson 2009: 1). This indicates that the technology was noted more for its end product, and similarity to stones of the same colour, than its raw material make up. "That *tjehenet* was primarily valued for the symbolic properties associated with its connotative meanings of luminosity and scintillation becomes clear when one considers its

predominance in the mythological topography associated with Osiris and the dead in general," (Bianchi 1998: 24).

Definite references to faience have only been documented in three places, with a possible fourth representing its manufacture. The first textual evidence appears at Lisht in tomb shaft 879, as mentioned in Section 2.1.2.2. Another example is a funerary papyrus from the 19th Dynasty that refers to Qn-hr (Qennou) as the 'director or overseer of faience makers' (Bellion 1987: 320, Marucchi 1891). There are also two stelae in the National Museum of Scotland, which belonged to Rekhamun, whose title as the 'faience maker of *Amon*' differs from the others (Nolte 1968: 7, Gaballa 1979: 45, Nicholson and Peltenburg 2000: 179). The last piece of evidence is a tomb (TT36) that belonged to Ibi (*Aba*), which possibly depicts faience-making at Thebes (dating to the 26th/27th Dynasty) (Davies 1902, Nolte 1977: 138-142). This depiction shows one man grinding something while another makes a piece of jewellery (Nicholson 1998: 56). However, this evidence is uncertain, since there is no text accompanying the image, and it may refer to something other than faience.

The colour of faience is what made the material so important to Egyptians. Its colour, brightness, and shiny surface replicated gemstones and probably added to its appeal and prestige (Tite *et al.* 2002: 585). In replicating the colour of lapis lazuli, faience could have taken on whatever significance was assigned to the stone. This phenomenon was observed in Mesopotamia, where green stone shared the same magical properties as the material (glass) that matched it, meaning that the colour was the significant factor, not the raw material (Crummy 2010: 55). Lapis lazuli, and therefore faience's blue colour, is often interpreted as symbolizing life, good health, protection against evil spirits, fertility, and rebirth (Friedman 1998: 15, Tite and Shortland 2008: 57, Wilkinson 1994: 107 and 116).

Blue, green, and the various shades in between, are the most common colours found in faience and this range of colours is one of its most identifiable features. In Egypt, blue was considered very prestigious (especially in paint) (Baines 1985: 288). The colour may explain why it was made into particular objects (Patch 1998: 43). Also, the way that the colour of faience was created was no doubt amazing to Egyptians, as Friedman (1998: 15) states, "the faience paste must have seemed magical: it entered the kiln dry, dull and almost colourless but emerged after firing brilliantly transformed".

2.1.4 Previous Research

Faience studies have been undertaken since the early 20th century, with Petrie and many other archaeologists making observations on the material and its production methods. Researchers from many other disciplines have also worked on faience, from ceramicists and chemists to ethnographers, and they have generated new information and perspectives on the material. However, many of their findings are questionable, or at the very least, out dated. Faience can only be properly studied using modern scientific methods, which were not developed a few decades ago. These researchers were leaders in their fields; however, new information and technology provides an opportunity to modify their theories. Some of these studies will be reviewed in this section, in order to provide an overview of the research that has taken place, and develop a background to this research. The key topics that will be discussed are: the variants of faience, recipes and replication, and the different analytical methods that have been utilised to develop our understanding of faience.

2.1.4.1 THE VARIANTS OF FAIENCE

Many researchers have proposed typologies of faience based on visual differences. The most prominent is Alfred Lucas (see Lucas and Harris 1962: 161-165) who divided Egyptian faience into different types based mostly on colour, but said very little about the methods of manufacture. The first category or type was the common blue glazed faience with a white core, which was referred to as ordinary faience. A further six variants, labelled A through F, were then proposed. Variant A is ordinary faience except a thin layer of fine ground quartz or sand was applied between the coarser core and the glaze (the interaction layer). B, C, and D were typed by colour variations; B-black, C-red, and D-deep blue. Variant E is a glassy faience and has no glaze (technically not actually faience, Nicholson 1998: 55). Variant F is lead-glazed as opposed to an alkali-glazed faience.

In 1985 Kaczmarczyk and Lahanier analysed samples from the Ashmolean and Louvre museums using x-ray fluorescence and atomic absorption. This research was undertaken to determine the usefulness of Lucas's faience variants, and they concluded that the classification system of Variants A through E was not satisfactory. They suggested a modification to Lucas's original suggestions by dropping Variants B, C, and D as they are only distinguished by colour. Also Kaczmarczyk and Lahanier (1985) suggest that Variant E should be dropped, as it is not another form of faience, but a type of imperfect glass, according to their analysis (confirmed by Nicholson 1998: 55). They determined that 'ordinary faience', as a term, should be kept for faience body material that shows no intentional

pigmentation (Kaczmarczyk and Lahanier 1985: 98). Variant A can be retained but extended to include faience that has an intermediate layer of any colour interlinking the body and the glaze. The greater faience research community has accepted the conclusions presented by Kaczmarczyk and Lahanier (1985). However, a few other variants were dropped by other studies and Lucas's variants were streamlined even more.

The term 'ordinary faience' is still commonly used in current research today. However, most of the other variants, such as Variants A through C, have been abandoned for faience research. Variant D is still used occasionally by some researchers (Shortland 2000). The discovery of the 'new' glazing technique of cementation that researchers were not aware of until its rediscovery in Iran (see Section 2.1.4.2), and the realization that glass technology was applied to faience and increased the colour palette, made these variants obsolete. Variant E was eventually ruled out because it lacks glaze, and Kaczmarczyk and Hedges dismissed Variant F in 1983. Although Lucas's variants were discredited by subsequent studies (Kaczmarczyk and Lahanier 1985: 98), his work is still considered a major building block for faience research, and is often referenced.

2.1.4.2 RECIPES AND REPLICATION

Binns *et al.* (1932) were the first to create a basic formula for the reproduction of efflorescence-glazed faience. However, the researchers did not take into consideration the technical authenticity of the exact formula used by the Egyptians, rather they approached it as ceramicists who wanted to replicate a technological process. The process they created was very basic and only consisted of a few steps, possibly holding true to the ancient methods. The paste's and glazes were created using soluble fluxes and colouring material that mimicked the texture and colour of Egyptian beads and rings that the researchers inspected (Binns *et al.* 1932: 271). The first step was to produce the paste, and the following recipe was found to be the most successful:

Godfrey feldspar	34.20	Sodium bicarbonate	5.30
Ground flint	34.20	Copper carbonate	2.60
Georgia clay	10.50	Powdered dextrine	7.90
Sodium carbonate	5.30		

Once the paste was complete, the beads were rolled. The second step was the firing, which took place at various temperatures and for different durations, with

the best temperature range between 800-1000^{o} C and the best time being around three hours (Binns *et al.* 1932: 271). The results were very close in colour and structure to the Egyptian pieces (Binns *et al.* 1932: 272). Overall Binns *et al.* (1932) got the recipe right, except for the addition of clay, which was not added to faience until the Greco-Roman period (Nicholson and Peltenburg 2000: 189). Very little has changed in the basic formula and firing temperatures since this study.

Noble (1969) intended to reproduce Egyptian blue faience, but unlike Binns *et al.* (1932) he took into consideration the way that Egyptians would have manufactured faience. Noble succeeded in reproducing faience by mixing natron (from an ancient source, King Tut-ankh-amun's funeral cache) with copper oxide into the ground quartz to form the body, and a little water was then added. The amount of water was properly determined based on the pastes workability, too little and it cracks, too much and it slumps (Noble 1969: 436). After shaping, the material was left to dry. At this point the soluble alkali salts migrated to the surface of the object and formed the crust that is very distinctive of efflorescence glazing. The sample was then fired in an oxidising atmosphere at around 950^{o} C, which causes the powdery crust to fuse together to form a glassy layer of glaze. The formula Noble employed is as follows:

Feldspar (ground)	40 grams	Flint (ground)	20 grams
Fine white sand (ground)	8 grams	Sodium carbonate	6 grams
Sodium bicarbonate	6 grams	Whitening	5 grams
Bentonite	2 grams	Copper oxide	3 grams

Noble even produced a second type of faience which was semi-glass and very similar to the 'glassy faience' type referred to by Nicholson (1998) and many other researchers. This type of faience was theorized to be the precursor to true glass (Noble 1969: 437). Noble created this type of faience by changing the ratio of carbonates to the silica component in the mixture. The carbonates do not migrate as easily to the surface, so they fuse within the core causing colour uniformity throughout the piece. This formula (Noble 1969: 427) is as follows:

Flint (ground)	20 grams	Fine white sand (ground)	8 grams
Sodium carbonate	3 grams	Sodium bicarbonate	3 grams
Bentonite	2 grams	Copper oxide	1.5 grams

This research was successful in everything it set out to do. However, there is still the need for further work. Although the results were adequate and the experimental material was similar in appearance to the archaeological one, chemical analysis was not properly undertaken. The samples were ground down and a general bulk analysis was conducted, an approach that is not appropriate for faience material, as each layer can have a different composition. So even though the new material matched the archaeological material on visual inspection, the chemical analysis could lead to very different results. Importantly, the copper may not have migrated in the way that was proposed by the research. How does one know how it migrates, without looking at all the layers, one at a time? An experiment to understand the copper migration was conducted and the results are presented in Chapter 5 (Section 5.4.1).

It should be noted that in some cases the recipes and reproduction of faience were aided by ethnographic studies. This includes Wulff *et al.* (1968) who rediscovered the self-glazing method of cementation. This method is also referred to as the Qom method since it was first observed at Qom, Iran. The inhabitants used cementation glazing to produce bright turquoise donkey beads. These beads were formed from a mixture of finely ground quartzite and gum *tragacanth,* which was dissolved in water and fired to about 1000^{o} C, whilst buried in a glazing mixture, which consisted of plant ash, lime, quartz, copper oxide and charcoal. Wulff *et al.* (1968) suggested this method could have been used in antiquity as far back as the Middle Kingdom (see Table 2.1).

The discovery of the cementation glazing method led to the attempted replication of the procedure by Vandiver (1982). This research centred on replicating the self-glazing methods of cementation and efflorescence, in order to characterize the manufacturing techniques used in the sample's production. The research also attempted to develop an understanding of the sequence of faience's technological development by analysing over 600 faience objects that date from the Predynastic to the Roman Period in Egypt (Vandiver 1982: 167). This analysis was completed by low-powered optical microscopy, and a few samples were analysed by scanning electron microscopy with energy dispersive x-ray spectrometry (SEM-EDS). The optical microscope aided in determining the body characteristics of hardness and particle size distribution. SEM-EDS was used to determine the chemical composition of the samples. Vandiver found that the composition of Egyptian faience was relatively constant throughout the time surveyed, however the way the body and glaze was utilised changed over time. Vandiver acknowledged the limitations of this research as it only analysed two collections, and the research needed to be verified

by future analysis. It is the hope of this current research to continue the investigation that Vandiver requested.

Tite *et al.* (1983) also attempted to replicate the self-glazing methods. Their research successfully reproduced beads made with cementation and efflorescence self-glazing methods in a laboratory setting. These glazes were characterised on the basis of their microstructure and composition of the glaze phase. These experimental samples were then compared to four faience objects from Egypt (Tite *et al.* 1983: 17).

The cementation (experimental) samples were produced by first forming the beads of ground quartzite, and then covering them with the glazing mixture in a porcelain crucible, followed by firing at 1000^{o} C in an oxidising atmosphere for about two hours (Tite *et al.* 1983: 18). The efflorescence sample was produced with about 80% of its weight being quartz sand (<250 microns diameter) or ground flint (<50 microns in diameter), plus 20% by weight of a glazing mixture comprised of sodium carbonate (6.5%), sodium bicarbonate (6.5%), calcium carbonate (4.0%), and copper oxide (3.0%). These beads were prepared with a sufficient amount of water added to make a paste, then fired at 980^{o} C for about two hours in a furnace with an oxidising atmosphere (Tite *et al.* 1983: 18). The efflorescence samples displayed a fragmented quartz core in a continuous matrix of glass, with a surface layer of quartz-free glaze when inspected with SEM. SEM was used to distinguish the phases/layers of the samples by their atomic number. The darker areas (silica) were at a lower atomic number than the lighter areas (glass). These phases were then quantitatively analysed using an electron microprobe (EM) coupled with an EDS system.

This section has presented a general progression of the practice of faience reproduction from the 1930s to the 1980s in the seminal publications, which form the backbone of current faience replication. The first stage was to select a recipe that worked and produced the desired colour and ceramic characteristics, eventually conforming to what may have been the general practice of the people who made faience in antiquity. The second stage, which was due to the rediscovery of an ancient glazing method in modern times, led to attempts to replicate the procedure. Finally, this was followed by the use of analytical methods to determine how closely the experimental samples compare to the archaeological ones.

2.1.4.3 ANALYTICAL METHODS

Many different analytical methods have been applied to faience, to determine every aspect of the material. This includes the raw material sources, firing

temperatures, glazing methods, comparison with experimental replicas, and much more. There are a vast number of publications on the analysis of faience. Only a few will be discussed here, to represent the variety of analytical methods utilised for understanding faience.

One of the earliest scientific papers was by Aspinall *et al.* (1972), who attempted to analyse faience beads from different regions with neutron activation analysis (NAA). They hoped to improve the methods used for determining how faience was made, by reanalysing the beads from Stone and Thomas's (1956) research. The research found that there was a general agreement between the current research method, and the one, which took place fifteen years earlier (even with different sampling methods). The main difference was the initial research only took place on a small portion of the bead, and this research used the remainder of the same sample (Aspinall *et al.* 1972: 31). Even though this research was deemed to have been successful, the use of NAA is rather difficult to expand upon in faience studies, as the material becomes radioactive, and therefore inaccessible for many years after the research. If there are other means available for analysis, such as SEM, similar results can be achieved as with NAA, however with less sensitivity.

Other attempts were made to determine the chemical composition of faience material with the use of energy dispersive x-ray fluorescence analysis (EDXRF) and atomic absorption spectrometry (AAS). These two methods were used by Foster and Kaczmarczyk (1982) to analyse fifty Minoan faience pieces from the Ashmolean Museum in Oxford. Also, Pollard and Moorey (1982) utilised EDXRF for analysing Egyptian and Near Eastern faience from the Ashmolean Museum. The research conducted by Foster and Kaczmarczyk (1982) was one of the first projects to use more than one method of analysis, acknowledging the limitations of one method and trying to compensate for it with another method. As EDXRF is really only suitable for surface analysis, the use of AAS improved the analysis of soda, magnesia, and alumina concentrations. This way they were able to double-check their results to determine the accuracy and precision of the method used on the bulk of their samples.

The success of using multiple analytical methods by Foster and Kaczmarczyk (1982) led to the largest technical study on Egyptian faience by Kaczmarczyk and Hedges (1983). They analysed and defined the range of compositions found in Egyptian faience by analysing 1,200 samples ranging from the Predynastic to Roman times. They used x-ray fluorescence spectroscopy (XRF), which is rapid and non-destructive, and AAS (only 60 samples). Elements measured by XRF were: silica, sulphur, chlorine, potassium, calcium, titanium, vanadium,

chromium, iron, cobalt, nickel, copper, zinc, arsenic, strontium, silver, tin, antimony, barium, lead, and bismuth with the exception of soda, magnesium, and aluminium. The elements covered by AAS in 53 samples of faience bodies and seven glazes were soda, magnesium, and aluminium (Kaczmarczyk and Hedges 1983: 1). This was done to determine the most common elements within Egyptian faience, and therefore identify imported faience based on different elements present in the form of impurities. Another aim of this research was to understand the change in faience technology over its 4,000 years of production, and to Egypt's technical tradition.

In using XRF and carrying out non-destructive analysis, the researchers only analysed the surface of some core samples. XRF is limited to surface compositions analysis, but this was all the researchers were interested in. AAS is a solutions method, which means the whole sample is ground down and made into a liquid. This method has very good limits of detection but is more appropriate for bulk analysis of the bead, as it is difficult to separate the layers (core, interparticle, and glaze). The researchers also used SEM and optical microscope to determine probable methods of manufacture, however they did not use it for chemical analysis.

After Kaczmarczyk and Hedges (1983), SEM analysis became one of the most common analytical methods used in faience analysis. Shortland and Tite (2005) undertook SEM analysis on fourteen faience vessel fragments from the Ptolemaic Roman Period, which were excavated at Memphis, Egypt. These samples came from the Ashmolean Museum in Oxford and were collected during Petrie's early twentieth century excavation of a series of kilns in the area. It is theorised that these kilns were used for the production of pottery and faience due to the abundance of faience wasters, saggars, and other kiln debris. By using SEM-WDS (wavelength dispersive spectrometry) analysis, the composition and microstructure of each fragment was recorded, and this allowed conclusions to be drawn about the production methods of the vessels studied (Shortland and Tite 2005: 31).

The current excavation by Nicholson in Memphis has successfully identified kilns in this region, which is very important for faience research, as there are very few known throughout Egypt. However, the material that was analysed for Shortland and Tite's (2005) research came from Petrie's excavations, and the recording is known to be inconsistent. Another problem with this research is that fourteen vessel fragments is too small a sample to define such a long time period.

Following on from their previous work, Tite and Shortland (2008) compiled a diverse series of papers and data sets in order to combine analysis of faience from many different regions and time periods. They also combined the historical and archaeological contexts with the material science analysis to produce information on

each data set. For each group of material the microstructural data was utilised to provide information on the raw materials used and the methods of fabrication. The primary aim of this research was to identify the similarities and therefore the differences in faience technology. The results of this compilation can be found at www.rlaha.ox.ac.uk/downloads/ (Tite and Shortland 2008: 15).

The primary techniques employed in this research were SEM or electron microprobe (EM) with WDS or EDS. In order to analyse the glaze layer and the core material, polished cross sections were completed. SEM was completed in backscatter electron mode (BSE) in order to make the different phases visible, based on their atomic number. The glazes and interparticle glass were analysed using WDS. The sodium was completed first to decrease the loss of soda during the analysis (Tite and Shortland 2008: 19). Other forms of analysis used include: AAS, XRF, laser ablation inductively coupled mass spectrometry (LA-ICP-MS), inductively coupled plasma atomic emission spectroscopy (ICP-AES), fast neutron activation analysis (FNAA), proton induced x-ray emission (PIXE) and lead isotope analysis to provenance the lead source for faience beads that contain lead.

Several conclusions were drawn from this research, including the discovery that the composition of faience glazes can be different from those of the plant ashes used to produce them. The Na_2O/K_2O ratios are frequently higher in the glazes than in the plant ash from which they were produced (Tite and Shortland 2008: 39). Furthermore, the glazing method chosen in antiquity may have been based on the size of the object being produced. The smaller the item (such as beads) the more likely that cementation was used; larger items such as bowls and tiles would have been created with the application method; and efflorescence would have been used for both large and small items (Tite and Shortland 2008: 208).

This section discusses only a few of the publications on analytical methods used for understanding faience. The ones presented here show the gradual progression from single methods to multiple methods of analysis. They also show that some methods were considered to be more favourable at certain times, such as NAA, which is rarely used now. In the 1980s, a new wave of analysis was underway, and there was a focus on collections held at museums such as the Ashmolean in Oxford. Three separate projects were undertaken on faience from Egypt, the Near East, and Greece (Foster and Kaczmarczyk 1982, Pollard and Moorey 1982, and Vandiver 1982). Almost all of them used the same analytical methods EDXRF, AAS, and SEM-EDS but they drew very different conclusions.

2.1.4.4 DISCUSSION

The overall conclusion of past research is that a much more holistic approach needs to be implemented in this current research. Most of the research that has been undertaken had singular goals, such as discovering how faience was made, exploring the possible origins and distributions of the material, and methods of classification and analysis. The most beneficial research on faience is one that can encompass all of the above aspects. There have been some attempts to achieve this, such as Kaczmarczyk and Hedges (1983). However, their analysis is now brought into question, as the conclusions were based only on surface analysis. The most recent attempt was by Tite and Shortland (2008) in which they tried to combine analysis from several different regions, time periods, and methods. This research project will take in to consideration such attempts, and try to expand on the information gained by many different techniques of analysis, with specific interest on the raw materials used in faience production.

2.1.5 Raw Materials

The selection of raw materials used by faience workers was incredibly important for the end product, since it had an effect on the workability of the material, and the appearance of the glaze. Understanding this selection process is very important for researchers trying to study production methods used over time. As Shortland (2000: 43) stated, “only by accurately ascertaining the starting materials is it possible to determine the full production process and assess the amount of labour, degree of selection of raw materials and the various processes involved”.

The main raw materials that were used in faience are silica-lime-soda, with the addition of colourants and impurities. The average ‘ordinary’ faience is comprised of 92-99% silica, 1-5% calcium, 0.5-3% sodium, and minor quantities of copper, aluminium, titanium, magnesium, and potassium (Vandiver 1982: 107). There were several different sources for each main constituent. Silica could come from either crushed quartz or sand. The soda source was either plant ash or natron, and lime could be introduced to the mixture from either the sand or plant ash. The last and possibly most important raw material was the colourant, which was commonly copper, although after the New Kingdom, other options became available. All of the possible sources of the main raw materials will be discussed in this section.

2.1.5.1 PROCUREMENT

When faience production first began, it might have been an institutionally affiliated or state-run craft, which would have procured the required raw materials in bulk. Some of the raw materials might have been collected from desert regions requiring state-controlled campaigns (Bianchi 1998: 22). These missions were probably sent to collect materials for many different industries at the same time. Such trips went regularly to the Sinai, where copper would be collected along with turquoise. By-products from copper smelting and manufacture would have been utilised as the colourant for faience materials, therefore faience benefited from such campaigns. However, the vast majority of the raw materials necessary for faience production were probably procured from the local landscape, since sand and quartz are common in Egypt along with lime, and soda (Nicholson 2009: 2, Tite and Shortland 2008: 45).

2.1.5.2 SILICA

Silica is the main constituent of faience; it varies within the interparticle glass from 92% to 99% and also makes up the entire core of the objects (Tite and Shortland 2008: 203). Silica, from either sand or crushed quartz, gives the faience object its shape (Nicholson and Peltenburg 2000: 187). As mentioned earlier (Section 2.1.4.2), flint and feldspar were used as the silica component for experimental replication (Binns *et al.* 1932, Noble 1968, Tite and Bimson 1986). However, there is no evidence that flint was used as the silica source in Egyptian faience as it would be compositionally different to the silica component found in archaeological samples (Hammerle 2008).

Silica sources include the readily available desert sand, which is characteristically impure and can include limestone, iron, aluminium, and titanium as impurities (Nicholson 1998: 50, Tite and Shortland 2008: 37). The other possible source of silica is crushed quartz, which is considered to be of a higher purity than sand (free of impurities) and can lead to a clean dazzling white body material (Nicholson 1998: 50). The quartz pebbles would have been crushed and ground down to improve the workability of the paste (Nicholson and Peltenburg 2000: 186). To make this process easier, quartz pebbles were often heated in the kiln to break down their structural integrity and make it easier to grind them (Nicholson 2007: 134). It should be noted, however, that even if quartz was used, impurities might still have been present from the alkali flux used along with contamination from the grinding tools (Rehren 2008: 1350, Tite and Shortland 2008: 37).

The key to determining whether faience was made with quartz pebbles or sand is to inspect the faience object with a microscope, to determine if the grains are angular or rounded (Aspinall *et al.* 1972: 27). If they are angular, then the source was crushed quartz because the particles would be fractured and shattered due to the crushing process. If the particles are rounded, then the source was sand. Also the impurities present could indicate the silica source; thus traces of iron, aluminium or titanium suggest that the source was sand. However, there are varying shades of grey in such analyses, and this will be discussed in Chapter 5 below.

2.1.5.3 ALKALI

The alkali is the second most important ingredient in faience production. It is the network modifier, meaning it helps to bind the silica and calcium together (Nicholson 1998: 51). A very low percentage of alkali (0.3-5%) was needed for faience because it was only used to lower the firing temperature, and not to create glass, which requires larger quantities of alkali. There were two possible alkali sources: plant ash and natron (Nicholson 1998: 50). A third option for the alkali quantity in faience is a combination of these two raw materials, which is usually described as a mixed alkali. According to Tite *et al.* (2006: 1284) the use of mixed alkalis, which becomes evident in the second millennium BC, "is characterized by potash contents that are usually a little higher than those of soda, and by low lime and magnesia contents".

Plant ash has been used in faience production since its inception in Egypt from the fourth millennium BC onwards (Tite *et al.* 2006: 1284). The plant ash comes from soda-rich plants that are salt-tolerant and halophytic (Tite *et al.* 2006: 1285, Tite and Shortland 2008: 204). The plants most commonly used belong to the *Salsola soda, Salsola jordanicola*, *Salsola vermiculata* and many other species, which commonly grow in the desert and coastal areas around the Mediterranean (Tite and Shortland 2008: 38). These plants have a high content of carbonates and bicarbonates, which are important for faience production as 'network modifiers' (Tite *et al.* 2006: 1284). These plant ashes have a complex mineralogy, including many impurities, which can have an effect on the process of faience production. There are many factors that can determine the composition of plant ash, such as the plants' species, the season in which they were harvested, where they grew, whether the stalks or leaves were used, and how the plants were actually ashed (Tite *et al.* 2006: 1285).

Wadi Natrun is just northwest of Cairo and was the source of natron (*trona*, as mentioned in Chapter 1) for most of Egypt and the Near East since the fourth

millennium BC (Shortland *et al.* 2006: 521). Natron occurs naturally along with other salts at Wadi Natrun, including carbonates, sulphates and chlorides of sodium (Shortland 2004: 498). The only significant ones for faience production are the carbonates and bicarbonates, as stated above regarding plant ash (Tite and Shortland 2008: 42). There were many uses for natron, including mummification, medicine, soap and the vitreous materials industry (Shortland *et al.* 2006: 521). Natron contributes little else to faience other than soda, this is because, unlike plant ash, it has very few impurities (Tite and Shortland 2008: 42). This fact has been used in determining which alkali was used in faience production.

Another determining factor is based on the presence and quantity of magnesium; if it is present in large quantities, then the alkali source would have been plant ash, and if low, the alkali was natron (Nicholson 1998: 50, Shortland 2000: 45, Shortland *et al*. 2006: 521). Shortland (2000) has also suggested that there might be correlations between colourants and alkalis: copper blue and potash, and cobalt and natron.

2.1.5.4 LIME

The last of the three main components of faience is lime (calcium oxide (CaO)) (Nicholson and Peltenburg 2000: 186). Lime comprises about 1-5% of the faience body and is considered a network modifier, like the alkali (Nicholson 2007: 135). There are several sources for lime (limestone, chalk, shells), and it can be present as an impurity in both sand and the plant ash, if used as the raw material sources for their components (Nicholson 1998: 50, Tite and Shortland 2008: 43). It is often believed that lime was added as an impurity in the other components, and was very rarely added separately (Tite and Shortland 2008: 43). To date, there is no conclusive way of identifying how the lime was added, or from what source. However, as part of this research, strontium isotope analysis was carried out to determine raw material sources, and the results will be presented in Chapter 6.

2.1.5.5 COPPER AS A COLOURANT

From the very beginning of faience production in Egypt, copper was utilised as the most common colourant. Copper and manganese are the only known colourants to be used before the invention/introduction of glass (Middleton 2009: 77). Depending on the firing conditions, copper could provide a variety of colours and hues. When an oxidised atmosphere was maintained in the kiln, the copper oxide produced a blue or green glaze, whilst a reduced atmosphere produced a red colour (Hodges 2000: 45, Noble 1969: 437).

There were many possible sources for copper in faience, including scrap copper metal and debris from metal working, to mineral ores such as azurite or malachite (Nicholson 2007: 135). One way to determine if scrap, corroded, or metal working debris were utilised, is by the correlation of tin and copper; since tin is an impurity found within metallic copper. Otherwise it is difficult to distinguish which raw material was used (Nicholson 2007: 135, Foster and Kaczmarczyk 1982: 147).

2.1.5.6 COBALT AND OTHER COLOURANTS

When glass was introduced during the New Kingdom, copper use started to decline and other colourants were introduced to faience production (Nicholson 2007: 146). These colourants included iron oxide or lead antimony for yellow, manganese oxide for purple/black/brown, and cobalt oxide for dark blue/purple (Noble 1969: 437, Tite and Shortland 2008: 43). Copper continued to be used for faience production, however some scholars have suggested that it was replaced to a certain extent by cobalt.

Cobalt was sourced from the alums of the Western Oases (Dakhla and Kharga) and was introduced into faience production in the second millennium BC (Rehren 2001: 483, Shortland and Tite 2000: 145, Shortland *et al.* 2006: 153, Tite and Shortland 2008: 206). These sources were utilised for faience and glass production throughout Egypt and the Near East until the Late Period. Compositionally it can be difficult to determine if cobalt was the main colourant used in a piece of faience, because very little of the element is required to make the desired blue hue. The only method for determining if cobalt was used as the colourant is by the lack of copper. If the faience item is blue in colour and if there is no copper present then the inference is cobalt was used.

2.1.6 Workshops

Once the raw materials were procured they were then taken to an area and combined and turned into faience. There is great debate regarding the locations in which faience was made. One theory is that faience was initially made in state-run or elite-run workshops (Bianchi 1998: 22), but then possibly, as it became more common and demand increased, it began to be produced in homes, using bread ovens (Eccleston 2008, Nicholson 2007: 146). There is also the possibility that the two types of workshops occurred at the same time in the same city, producing material for all social classes. The state workshops would have served the royal family and the elite, whilst the smaller workshops would have produced items for the general populace. There is archaeological evidence of workshops for faience at

sites such as Abydos (mentioned earlier in this Chapter at Section 2.1.2.2) and Amarna.

At Amarna, Nicholson excavated a portion of the site referred to as O45.1, including five kilns or furnaces that are on a scale and complexity so far unknown in Egypt (Nicholson 2007: 157). This site includes two furnaces/kilns 2 metres in diameter and a third smaller furnace/kiln, which was possibly a pottery kiln (Nicholson 2007: 157). Artefacts that were found at site O45.1 included: frit (for glass production, rather than the artefact types), glass rods, cylindrical vessel fragments, faience moulds, and misfired/misshapen faience objects (Nicholson 2007: 133). This site provided evidence that pottery, faience and glass could have been produced in the same area, although Nicholson (2007: 133) pointed out concerns with this hypothesis: “in a workshop where only moulds and faience pieces were being recovered and where there was a kiln beside it, the obvious implication would be that this was a faience workshop, but where other craft are present, using similar technologies, it is much more difficult to be certain whether any particular kiln/furnace was for any particular purpose”. The rare and complex nature of this site suggests that it was a state-controlled workshop (Nicholson 2007: 157).

There is evidence of faience and glassworking taking place within the same workshops at Amarna, and perhaps involving the same craftsmen, and overseen by the same officials. During the New Kingdom, when glass was first introduced into Egypt, it was probably a royal monopoly simply because it was rare, however by this time faience was commonplace and probably not as restricted as glass (Shortland *et al.* 2001: 147). The products of the same workshop were destined for two completely different socioeconomic groups (Shortland *et al.* 2001: 148). The combination of vitreous materials in the same workshops may have been an economic decision, because the same raw material resources were needed and the kiln structures would have been similar, meeting the needs of all material types (Friedman 1998: 17). Also, the raw materials could have been better managed, and distribution could have been controlled by administrators/overseers who would maintain stock supply (Bianchi 1998: 23).

There is little archaeological or textual evidence for the organisation of faience workers, other than that they were overseen by officials with state/temple titles (mentioned in Section 2.1.2.3) and organised into teams. The titles provided to these officials and the hierarchy that was followed was thus: the chief faience worker (*hry irw hsbd*) who oversaw the other workers, and was under the control of the overseer of faience workers (*imy-r irw hsbd*) (Shortland *et al.* 2001: 155). Because these titles were given by the state/temple, it suggests that there was official

administration controlling their workshops: “This might suggest that tight administrative control was also exercised on the production of faience and certainly the faience workers seem to come under the administrative structure” (Shortland *et al.* 2001: 156). However, there would also have been private sector purchases or trade of faience that would not have been controlled by the administration or state.

The officials appear to have been more highly rewarded than the craftsmen themselves: “The individuals performing the actual work, those who were in direct contact with the material – be it stone, metal, or faience – received much smaller amounts of daily rations as payment than the overseers in charge of the operation” (Bianchi 1998: 23). This indicates a state run bureaucratic hierarchy for faience rather than a small-scale production.

2.1.7 Production Methods

Due to the lack of textual evidence, the only way to obtain any information about faience making in ancient Egypt is through the archaeological remains. This is limited because the end product (beads, and other objects), kiln remains, moulds, and waste are all that remain. There is no known recipe for faience and, from compositional analysis, it is apparent that there were many variations. This indicates that there was no precise formula, only a rough guideline for how to make faience, and craftsmen also utilised several techniques to produce one piece (Nicholson 1998: 54, Nicholson 2009: 2, Nicholson and Peltenburg 2000: 191).

What is known is that faience is basically a ‘cold’ technology bearing more similarity in its production steps to pottery making and stone working than to glass-making, which requires heat to form (Nicholson 1998: 51, Nicholson 2009: 2, Peltenburg 1987: 20). Faience is a complex material that is similar to glass compositionally but the process is completed in a shorter time than required for glass production, because the glaze is the only thing that becomes vitrified (Nicholson 2009: 6, Vandiver 1998: 132). There is a clear connection between gemstone production, glazed stone production, and faience production, since they all utilised the same basic techniques (Nicholson 2009: 2). The production methods for faience manufacturing will be presented in this section. It is important to bear in mind that these steps are theoretical, and are based purely on the scientific analysis of faience artefacts.

2.1.7.1 GRINDING AND FORMING

The first step after collecting the raw materials was to mix them together; this would have involved grinding/crushing the material together thoroughly, ensuring the

mix became homogeneous. This would have been especially true for the silica component be it sand or quartz pebbles, as they both would have to be broken down to a fine powder, using an appropriate grinding tool such as the grindstone found at Harappa in a factory context (Harappa 2006, Nicholson 2007: 138, Rehren 2008: 1346). The particle size of the faience material is very important, since fine particles allow for retouching and reworking faience pieces more precisely than is possible with coarser material (Griffin 2002: 332, Nicholson 2007: 138).

The next step would have been the addition of water to the powder to form a thick paste (Nicholson 2007: 138). At this point a binder could have been added to ensure adhesion of the particles and improve workability (Aspinall *et al.* 1972: 27), although there has been no real evidence for this practice. Alternatively they could have ground the material very finely so that it adhered well without any aid, as discussed in Chapter 7.

Once the paste was created, the item could be formed using two different methods: modelling and moulding. The material would have needed to be formed gradually and worked smoothly, as the workability of the paste is unlike clay and if worked or shaped too rapidly it can crack and split (Nicholson and Peltenburg 2000: 187). This is due to faience's thixotropic nature, meaning that the consistency is thick at first, and then the material becomes more liquid and flowing (Nicholson 2007: 112).

The first method of forming used for faience production, dating back to the earliest stages of the emerging technology, was modelling: the shaping of the object by hand whilst it was still wet (Griffin 2002, Nicholson 1998: 51). This technique also utilised forming over a core or patrix to form large bodied items such as the hedgehog and hippopotamus figurines (Nicholson and Peltenburg 2000: 181). Once the item was formed in the desired shape it was left to dry. Once the item had dried, a design could be abraded onto it at this stage with a sharp tool, or it could be immediately fired (Nicholson 2009: 3, Vandiver 1983: A108).

The second method is moulding (usually with open faced moulds), and this really only came into full effect in the New Kingdom, heralding mass-production (Nicholson 2007: 138, Vandiver 1983: A108). This involves the use of a mould or form as a template for the desired shape or design and usually allows for more detail on the pieces. The moulds were created by impressing a pattern into the wet clay or carving it into the desired shape before firing it (Boyce 1989: 165, Nicholson 2007: 139, Nicholson 2009: 3). These moulds could then be used repeatedly to make similar objects as the one that was imprinted (Lucas and Harris 1962: 158). This was normally done when the paste was still soft and slightly damp. The

material then dried out inside the mould or it could be removed from the mould and allowed to dry on a tray. If the item required any correction or touch ups before firing a sharp implement could have been used (Nicholson 2007: 139). The use of moulds helped to create sophisticated designs and complicated shapes, in great quantities and quickly (Nicholson and Peltenburg 2000: 188-189). Moulds allowed for the mass-production of faience rings, beads, amulets, and inlays (Lucas and Harris 1962: 159, Nicholson 1998: 52).

Once the faience object was formed, using either of the methods above, it then needed to be dried. Depending on the object, it would have had to dry either flat or on a stand. If it needed to be dried flat, it would have been placed in a shallow cloth-covered tray, because the cloth would be porous and allow airflow to either side of the object (Nicholson 2007: 139). The cloth would also absorb some of the moisture during the drying process and prevent the pieces from sticking to the tray (Nicholson 1993: 33). This has been hypothesised from fabric impressions on the reverse of some faience pieces (Nicholson 2007: 141).

2.1.7.2 GLAZING

There are three methods of glazing for faience material: application, efflorescence, and cementation. The last two methods are described as 'self-glazing', whereas the application method would have involved painting the glaze onto the faience core. Even though certain glazing methods were introduced or used during specific time periods, they cannot be compared to each other or used as a method of dating material found (Paynter 2009: 101). This is because there are too many variables that can affect the composition and the glaze outcome. Many researchers have also observed the use of several different glazing methods on one item, which can produce a confusing mixture of factors (Griffin 2002: 329, Nicholson 2007: 137, Vandiver 1998: 122).

The best way to determine the glazing method is by scanning electron microscopy in backscatter imaging mode, which creates a greyscale image where the intensity of the greyscale is directly proportional to the atomic number of the elements present, and helps to identify the three layers of the faience material (see Chapter 5). Efflorescence is characterised by extensive interparticle glass that extends through the core, while cementation glazing has a very distinctive three-layer structure with glaze, interparticle glass and core being obvious. The application method - the easiest to identify - produces a glazed layer and core layer with a very small interparticle layer being observable (Nicholson 2009: 5, Vandiver 1982). The glazing method can be determined based on the thickness of the interparticle layer

and the boundaries of all layers (Tite 1987: 24, Tite and Shortland 2008: 50). The only major difficulty in using this method is the faience object being studied/analysed needs to be cross-sectioned, which requires damaging the object, however this method can be used on objects already damaged.

2.1.7.2.1 Application Glaze

Application glazing occurs when the glazing mixture is painted on to the faience body or the body is dipped into the slurry (Nicholson 1998: 53, Vandiver 1982). This method of glazing was originally thought to be the only method used. This is due to early researchers, such as Petrie in the early twentieth century who, being familiar with pottery production, assumed that faience was made in the same way (Vandiver and Kingery 1987 b, Nicholson 2009: 4).

With the application method, there are obvious drips and flow lines on the glaze, and it varies in thickness (Nicholson and Peltenburg 2000: 190, Vandiver 1982: 168). Due to the way that the glaze is applied, the entire object is covered, however there are usually some traces of thinner coverage as a result of the kiln supports on which it rested while drying (Vandiver 1982: 168). Application-glazed faience is characterised by a softness of the body, due to the lack of interparticle glass, which binds the silica particles together in the core, giving the faience strength and structural integrity (Nicholson 1998: 54).

2.1.7.2.2 Efflorescence Glaze

Efflorescence is a self-glazing method, and Binns *et al.* coined the term in 1932 (see also Nicholson and Peltenburg 2000: 189, Vandiver 1982: 168). At the earliest stage of faience production, the glazing salts are mixed with the core material, then formed and dried. During the drying process the salts effloresce or migrate to the surface of the faience object, forming a crust that fuses together during the firing process, turning into glaze (Tite and Bimson 1986: 69, Vandiver 1982: 168). The glaze thickness varies depending on the length of time the salts are allowed to form (Nicholson 1998: 53). Efflorescence glaze works better for larger objects because the salts are mixed in with the body material, and therefore it neither needs to be completely covered with glazing powder (as in cementation) nor needs to be dipped or painted (as in application) (Tite and Shortland 2008: 54). Efflorescence glaze has extensive interparticle glass that makes the body harder by binding all of the silica particles together in the core. The glaze is usually very good, for the same reasons, as it is more thoroughly vitrified (Rehren 2008: 1347).

Efflorescence is characterized by rest marks and stand marks where the faience piece was set down to dry. In the parts of the object where the airflow was restricted, the salts cannot form, therefore no glaze or only a slight glaze will form where the object was resting (Nicholson 1998: 53).

2.1.7.2.3 Cementation Glaze

Cementation glazing is another self-glazing method. This method is also referred to as the Qom technique because it was first discovered at Qom, Iran in the 1960s (Nicholson 1998: 53, Wulff *et al.*1968). This method involves placing the body material within a vessel and covering it with glazing salts. During firing, the salts fuse together on the surface of the object and form the glaze (Tite and Bimson 1986: 69). Cementation glazing is very good for mass-production, since a large number of small items can be glazed at the same time. Cementation glaze can be identifiable by the naked eye or with the use of a microscope, as it leaves no drying or firing marks due to the item being embedded in the glazing salts and completely surrounded for full glaze coverage (Vandiver 1982: 169). Since the glaze seeps into the body from the outside, the glaze and interparticle layer are very apparent as a distinct section, juxtaposed with the core/body material (Nicholson 1998: 53).

2.1.7.3 DECORATION

There are several different forms of decoration for faience materials. The most common is applied in the form of black manganese or iron oxide paint, but there is also incised decoration, inlaying, and that which is imprinted from the moulds. The paint used to decorate faience is applied to the object before it is fired, because once it is fired, the colour becomes permanent and is contained within the glaze (Nicholson 1998: 54).

2.1.7.4 FIRING

Faience, frit, and glass are part of an ancient continuum of silica plus varying amounts of alkali, lime and copper. The difference between the three materials is the quantity of the alkali added, and therefore the firing temperature, which, in turn, affects the structure of the material (Table 2.2). They should, however be thought of as distinct materials in terms of their composition, since it would not be possible to turn faience into frit or frit into glass simply by further, or higher temperature, heating. They could only be changed into one another by the addition or subtraction of alkali.

Material	Description
Faience	Glazed non-clay ceramic predominantly made of silica with small amounts of alkali, lime and copper. Has a three layer structure consisting of a core, glaze, and interparticle glass.
Egyptian Blue Frit	Can be a naturally occurring pigment. Dominant crystalline phase is a calcium-copper tetrasilicate known as 'Egyptian blue' ($CaO.CuO.4SiO_2$) in a very limited matrix of glass.
Turquoise Blue Frit	The dominant phase other than quartz is a calcium silicate known as wollastonite ($CaSiO_3$), which is crystallised from the copper-rich glass matrix.
Glass	A hard, amorphous brittle translucent/transparent substance made by fusing together silica, soda and lime and cooling the product rapidly to prevent crystallisation. This crystallisation is often referred to as homogenous though there is slight compositional variations throughout the crystal structure.

Table 2.2: The continuum of silica, alkali, lime, and copper materials (after Tite 1987).

The process of firing faience leaves the material in a sintered state. This means that the faience material is heated sufficiently for two of the three layers (the glaze and interparticle glass) to melt into a liquid, which as it cools, binds the core/body together (Moorey 1994: 167). The body does not melt because it is almost pure silica, which has a melting point of 1710^{o} C (Shortland 2000: 1, Yatsenko *et al.* 1999: 271), a temperature too high to have been reached in antiquity. In order for the glaze and interparticle glass to form, the melting point of the silica needs to be reduced. This is accomplished by adding soda and lime as fluxes within the glazing salts, lowering the melting point of the silica in the glaze and interparticle glass layers to between 800^{o} C to 1000^{o} C, which is the temperature commonly thought to have been reached in antiquity (Nicholson 2009: 7, Paynter and Tite 2001: 240, Rehder 2000: 50). However, the higher the temperature reached, the smoother the glaze, and the deeper its penetration into items (Nicholson 2009: 8).

The kilns/furnaces that would be required to produce faience are rather basic, because the firing temperatures would not need to be especially high with the fluxes added in. The earliest and best evidence for firing structures from the Old Kingdom to the Middle Kingdom is at Abydos (see Section 2.1.2.2), where pits lined with broken bricks were possibly used for firing faience (Nicholson 2009: 8). The

kilns at Amarna are a variety of sizes, shapes, and designs, indicating there was no need for a specialized style (Shortland *et al.* 2001: 154). Even the techniques for firing the materials could have been quite simple, given that Eccleston (2008), for example, managed to replicate faience in a bread oven.

During later periods (especially the Greco-Roman Period) faience was produced in large quantities in Memphis at Kom el Qalama and Kom Helul (see Section 2.1.2.4; and see also Ashton 2008: 105, Nicholson 2001: 15). During his excavations of these sites, Petrie found kilns/furnaces, but as with his excavations at Amarna, there is no plan indicating where he found them. Currently, Nicholson is re-examining Memphis and has uncovered a number of kilns. During excavations, Nicholson (2001:15) also identified saggars (ceramic vessels), which were used to keep the glazed material free of dust and ash during firing. These saggars would have been stacked within the kiln in a specific design to maximize the firing of the artefacts (Kryuchkov 1995: 112). Kom Helul is a significant site for the understanding of faience production and is an on-going project.

2.2 Beads

Beads are some of the most common archaeological finds throughout the world, especially in Egypt and the Near East (Tait 2006: 23). The earliest beads date back to 60,000 BC and are some of the oldest human ornaments found (Sciama 2001: 1). Beads remain in the archaeological record for a significant amount of time, as they are small and usually made from such durable materials as ostrich eggshells, animal teeth, and bones (as in the case of some of the earliest beads found at La Quina in France (Dubin 2006: 21)). According to Liu (2006: 9), "Beads were probably the first durable ornaments humans possessed, and the intimate relationship they had to their owners is reflected in the fact that they are among the most common items unearthed from ancient graves". Due to their associations with burials, beads can be indicators of social status (displaying wealth), religion (amuletic or talismanic or apotropaic properties), group identity, and a desire for ornamentation (Gwinnett and Gorelick 1991: 187, Tomalin 2001: 299). Beads can also indicate trade routes and relations between peoples, as they travel great distances. Due to their small size and durability, beads were universally appreciated and collected by many ancient societies (Gwinnett and Gorelick 1991: 187, Liu 2006: 9, Sciama 2001: 7).

The rest of this section of the thesis, below, will aim to present background material on beads, with discussion of their history as an artefact, their method of classification, and the reasons why they are worth studying. Also, the importance of

beads to ancient Egyptians will be analysed, along with their functions and manufacturing techniques.

2.2.1 History

The history of beads goes back to the first human ancestors, and constitutes some of the earliest evidence for artistic abstract thinking ever discovered (Diamanti 2003: 8, Dubin 2006: 26). It is possible that the first beads were all organic, i.e. seeds, nuts, berries, and other items that would not have survived in the archaeological record (Diamanti 2003: 8, Dublin 2006: 27). Once beads began to be made out of more durable material, such as ostrich shells, it becomes more apparent how common and well-used beads were by the sheer number of beads left in the archaeological record.

Neanderthals are responsible for some of the earliest known beads found at La Quina, France, dating to approximately 38,000 BC. These beads are made from animal teeth and bones and were worn as pendants (Diamanti 2003: 8, Dubin 2006: 21). It was not until the Upper Palaeolithic that stone beads were used, since it was only then that technological advances took place in terms of the tools required to make them. This was the start of exploitation of the mineral world for coloured objects to be made into beads (Diamanti 2003: 8, Dubin 2006: 27, Wright and Garrard 2003: 267). Towards the end of the fifth millennium BC, glazed steatite/quartz beads were made as part of the emergence of 'pyrotechnology', which marks the point at which the mineral world began to be manipulated by humans to produce the beads they wanted (Kenoyer 2003: 19). This of course then led to the production of faience beads from the Predynastic Period onwards, and later glass beads, starting in the New Kingdom (Lucas and Harris 1962: 44).

2.2.2 Terminology and Classifications

There are very few well-developed typologies or terminologies for beads. The system of classification that has been both the most successful and the most commonly used was the first published by Horace Beck in 1928 (fully explained in Beck 1973). "This paper is written in the hope that it may assist in getting more uniformity in the description of beads" (Beck 1973: 1). In fact Beck's classification has been successful in creating uniformity and standardisation, and is now used in many different countries on beads from every time period.

For this research Beck's definitions will be utilised in order to be consistent with the bead research community. Therefore, certain terms will be used such as axis, an imaginary line through the centre of the hole of the bead, (Beck 1973: 2).

Length will be taken to refer to the distance between the two ends of the bead (Beck 1973: 3). Along with the terminology Beck (1973) developed a typological classification system, which has four divisions of beads and pendants: (i) regular rounded beads, (ii) regular faceted beads, (iii) special types of beads and pendants, and (iv) irregular beads and pendants. These categories are then subdivided into groups, subgroups, families and classes.

Division (i), i.e. the 'regular rounded bead', is subdivided into seven groups: circular, elliptical, ovoid, lenticular, plano-convex, semicircular, circular and flat (see Table 2.3, and Beck 1973: 6). These subdivisions are essentially based on the beads' transverse section and curved lines.

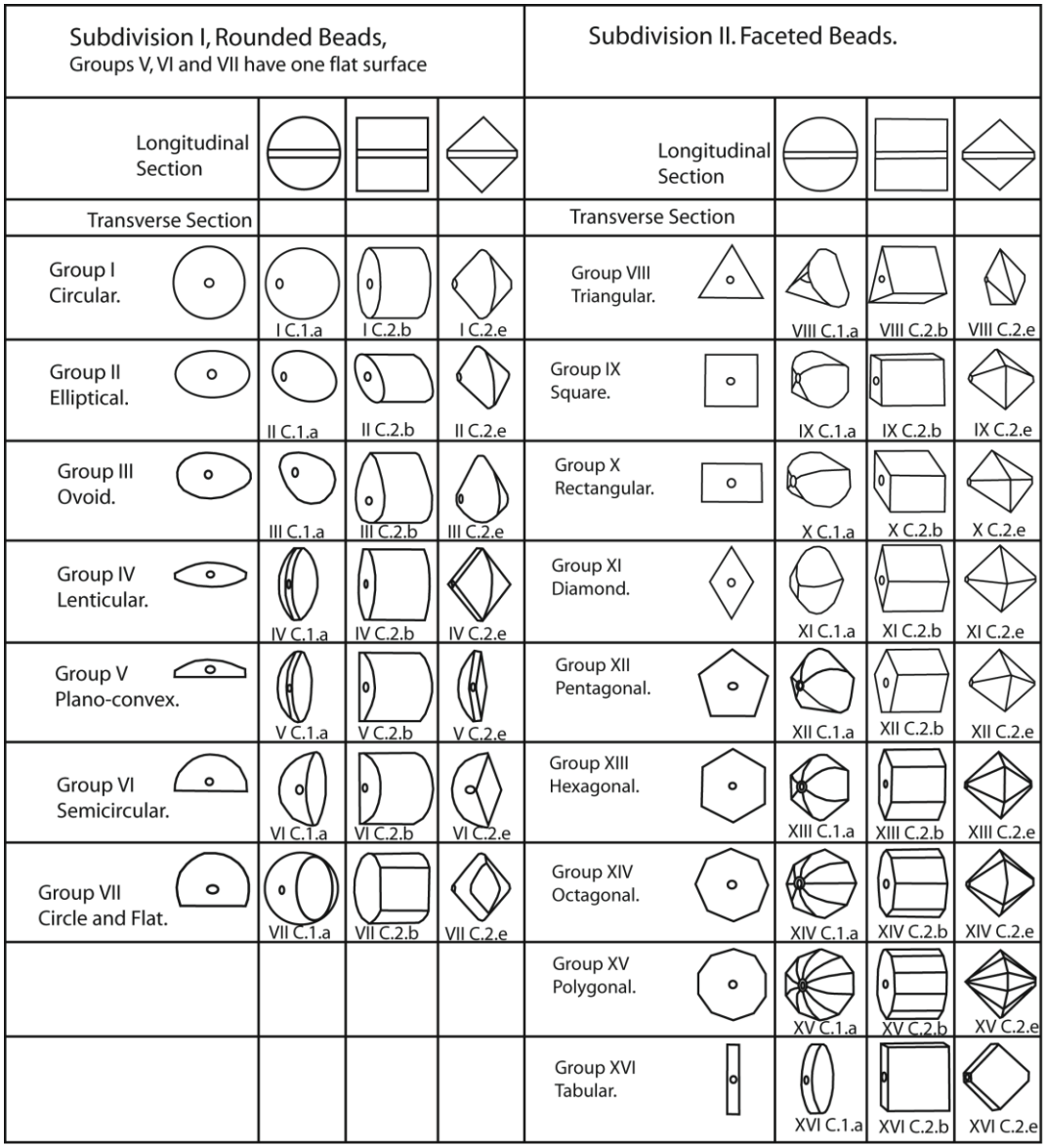


Table 2.3: Subdivision I and II of Beck's classification (adapted from Beck 1973).

Division (ii), consisting of regular faceted beads (a series of straight lines) comprises nine groups: triangular, square, rectangular, diamond, pentagonal, hexagonal, octagonal, polygonal, and tabular. These groups are then divided into four subgroups depending on the bead's length: disc beads, short beads, standard beads, and long beads (Beck 1973: 6). Division (iii), 'special' and (iv), 'irregular' represents all the beads and pendants that do not fit the above criteria. These beads and pendants are elaborate and very decorative. It should also be noted that it could be very difficult to determine what distinguishes a bead from a pendant, because of this the division (iii) is divided into 32 groups to attempt to distinguish each possible variation (Beck 1973: 11).

The bead type that will be referred to most frequently in this research is the most commonly found type of bead, the 'regular bead'. This bead has a simple geometric shape and of this type of bead the 'disc-bead' is the most commonly found in Egypt. The length of the disc bead is typically less than one third of the diameter of the bead (Beck 1973: 4). Regular long beads are the second most frequently found beads and are categorised by their length being at least 1.1 times the diameter of the bead (Beck 1973: 4).

2.2.3 Why Beads?

As stated earlier beads are common artefacts on archaeological sites and because of this they can be very important for understanding the culture to which they belonged. There are various contexts in which beads can be found, the two main ones being mortuary or settlement sites. The beads found in mortuary settings presumably belonged to funerary assemblages, and may have related to rituals in which the dead were honoured (Diamanti 2003: 10). Such funerary beads were either worn in life and used daily, or specifically acquired for death or the afterlife. Beads found on settlement sites indicate casual loss; it is easy to lose beads and difficult to retrieve them. It is also very difficult to apply any symbolic meaning to such beads as they are found in random contexts.

Beads are found in every culture, and might be regarded as the 'small change of civilizations' (Liu 2006: 10). Although ubiquitous, they are often considered to be prestige goods because of potential links with the ritual and religious aspects of a culture. Therefore, the study of beads can lead to the interpretation of exchange networks, since they are often traded (see Figure 2.1 and Theunissen *et al.* 2000). "Almost as soon as beads appear we find evidence of long-distance trade in materials used to make them" (Diamanti 2003: 8). The study of beads provides insight not only into the beads themselves, but also the people who

made the beads, those who traded them, and those who used them and deposited them in the archaeological record (Diamanti 2003: 8). In helping to understand trade, beads can also help to determine changes in societies, and in their social values, social organisation and economics (Wright and Garrard 2002: 267).

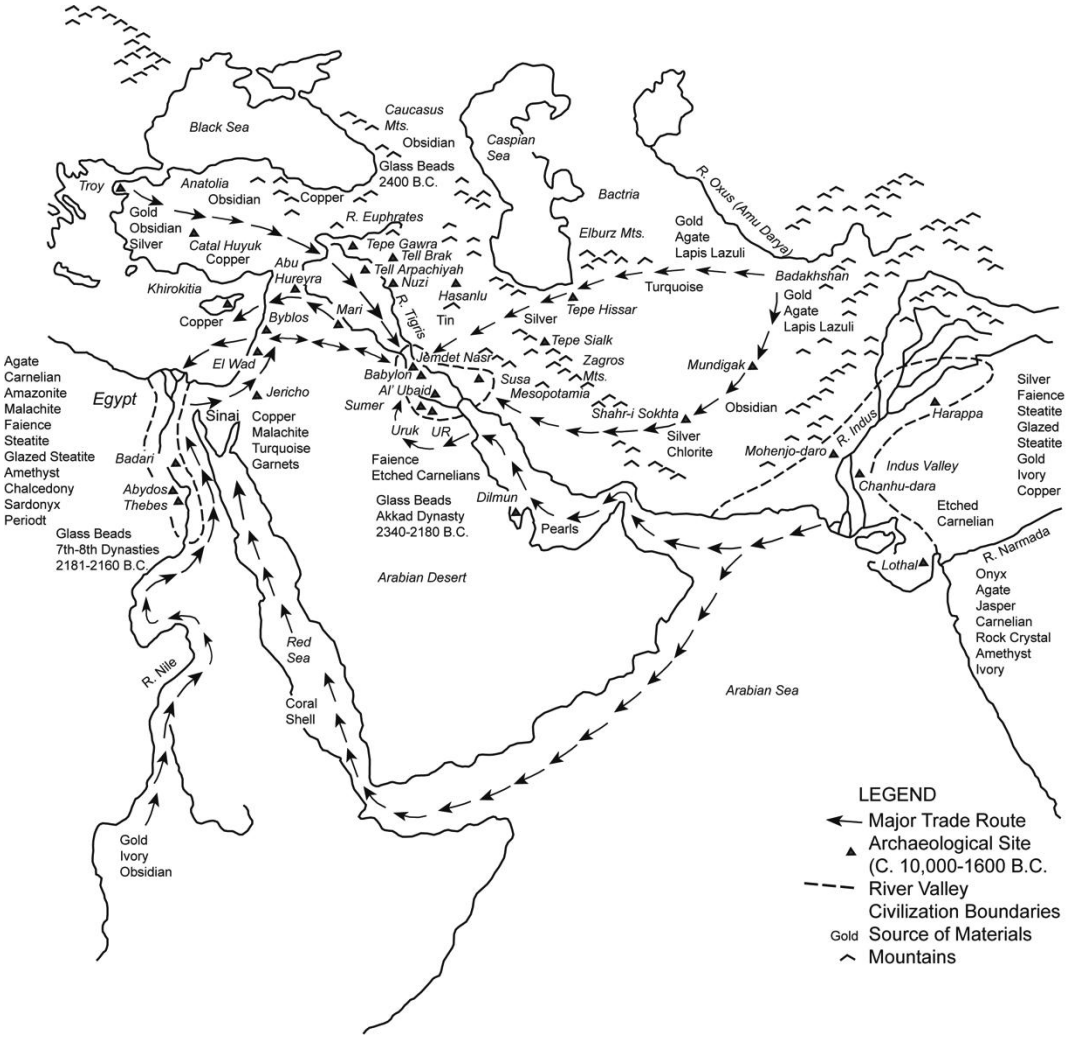


Figure 2.1: Distribution of ancient beads and bead materials (adapted from Dubin 2006: 35).

Beads can also be excellent indicators of social aspects such as personal adornment, ornamentation and identity. Decorating the body can indicate many different cultural factors, such as the act of belonging to a community, age, gender, sexuality, status, and power (Sciama 2001: 18). Beads can be symbolic and the association of beads with particular parts of the body can mean various things to specific communities. “Articles of personal adornment and other forms of art that had no practical use but were a means of symbolic communication” (Diamanti 2003: 8) could be understood by members of the community. This means that finding

beads in a burial context can visually represent the person's identity, and lead to interpretations of the culture to which the individual belonged.

2.2.4 Bead Uses and Their Importance to Egypt

Beads were created in Egypt as early as c.12,000 BP (Lucas and Harris 1962: 7, Petrie 1920: 49). The vast majority of beads produced during this time period were made of faience and belong to the category of disc-beads (Aldred 1971: 115, Bosse-Griffith 1975: 122, Vílímkova 1969: 45). Egyptians did not just use beads for jewellery, but also attached them to clothing, and to any other items considered worthy of decoration or in need of divine protection. According to Dubin (2006: 42), "The Egyptian word *sha* means 'luck' and *sha-sha* means 'bead' suggesting that beads were thought to have amuletic or protective properties, which would explain the Egyptian custom of using beads to cover almost every article of clothing and every part of the body".

Perhaps Egypt's greatest contribution to jewellery was the creation of intricate beadwork items, such as nets, dresses, mummy wraps and collars: "No other nation of antiquity produced such an enormous wealth of beads in so many different shapes and substances than Egypt" (Aldred 1971: 115). From the beginning of the Predynastic period to Ptolemaic times all levels of society, both sexes, and all age groups used beads for decoration, as an indication of economic or social status, and for amuletic purposes (Andrews 1990: 7, Andrews 1999: 67, Dubin 2001: 42, and Lucas and Harris 1962: 41). Even in modern Egypt blue beads are used to protect children, livestock, and in prayer (see, for instance, Lucas and Harris 1962: 41).

Egyptians used beads both in daily life and in the mortuary context. In funerary usage beads could both mark the social status of the individual for eternity, and provide magical protection (Taylor 2001: 20). These could have been the same beads that the individual wore in life, rather than being made specifically for burial purposes. The vast majority of the beads in Egypt probably served in life and death, as there was a complex religion and strong funerary culture that would have placed symbolic meanings on the beads, allowing their meaning to move from one realm to the next (Diamanti 2003: 12). For the same reason, however, it can be difficult to distinguish ornamental usage from apotropaic function.

In the period between the Predynastic and Old Kingdom, the development of techniques of bead making in Egypt gradually emerged, and the most common material was steatite (Tait 2006: 26). It was perhaps in the Middle Kingdom that some of the best Egyptian beads were produced, including some very small

examples with fine designs (Lucas and Harris 1962: 41, Vílímkova 1969: 20). This period is also generally considered the high point in Egyptian jewellery making and inlays (Tait 2006: 26). In the New Kingdom jewellery making techniques were similar to those in the Middle Kingdom, except for the introduction of glass (Tait 2006: 42).

2.2.5 Production Methods

Beads were made by a specific group of workmen whose only occupation was to produce faience, beads and jewellery. The faience maker (*baba*) would have worked with other craftsmen such as the bead maker (*iru weshbet*) and the necklace makers (*setro*) (Aldred 1971: 66). The beads would have been formed after the faience paste was mixed, as stated earlier, there are two methods of forming: modelling and moulding.

When beads are made with the modelling method, the paste is rolled by hand to produce the desired shape and size whilst the material was still wet (Aspinall *et al.* 1972: 28). If the desired shape was a ball bead, the material would then be pierced either while wet or when slightly dried, using a sharp implement (Nicholson 2007: 141). It is also possible that the beads were drilled when dried to produce the perforation. However, the latter would be a little more difficult, and could destroy the bead very easily if it went wrong. If the bead was a long cylindrical/tubular bead it could have been made by rolling the faience paste over a reed, and during firing this reed would then burn out, leaving a perfect perforation (Hodges 2000: 61, Nicholson 2007: 142). This method was first theorized by Petrie and was later supported by Lucas and Harris (1962: 45). The second method of forming a bead is moulding, which could also be used for pendant type beads, and became popular in the New Kingdom. Once the paste was prepared, it was then placed in a mould and left to dry. This method could be used to create beads with elaborate styles and shapes (Aspinall *et al.* 1972: 28). The beads would then be pierced or drilled to create the perforation. However, another method involving luting a loop of faience to the pendants would have been used in order to provide some of them with a means of suspension. Once dried, the beads were then fired, in the same way as other faience artefacts.

2.3 Summary

Several key points regarding the background of faience and beads are summarized here, to highlight their significance to the overall research. First of all faience is a confusing material terminologically and technologically (Lucas and Harris 1962: 156). The composition of faience is soda (0.5-3%) lime (1-5%) and

silica (92-99%) with varying amounts of other elements as impurities or colourants (Nicholson 1993: 9, Vandiver 1982). There were several sources for these raw materials. Silica would have been made from either crushed quartz or sand ground to a fine powder (Nicholson 1998: 50, Tite and Shortland 2008: 37). The soda would have been made from natron, plant ash or a combination of the two in a mixed alkali (Nicholson 1998: 50). Lime could have been added as an impurity in the other main components or as limestone, shell, and chalk added deliberately (Tite and Shortland 2008: 43). All of the raw materials could be locally sourced from the Egyptian landscape.

Faience has three distinct layers consisting of the core, the glaze, and the interparticle glass layer, which binds the other two together. The size of these layers depended on the glazing method used (Nicholson 2009: 5). There are three glazing methods: application, efflorescence, and cementation (the last two are self-glazers) (Nicholson 2007: 137). Once the raw materials are mixed, the paste is then formed using one of two methods, (modelling or moulding), then dried, and fired at 800-1000^{o} C (Paynter and Tite 2001: 240, Rehder 2000: 50).

The origins of faience are still debated, although the archaeological evidence so far points mostly to Northern Mesopotamia, where the oldest known faience material has been found (Henderson 2000: 181, Tite and Bimson 1987: 87, Paynter 2009: 93). However, greater innovation seems to be displayed in Egypt, in the development of methods of faience production over the course of time (Noble 1969: 435). Faience was then dispersed throughout the Mediterranean and Europe, with local production methods eventually emerging (Stone and Thomas 1956: 40).

Faience has been used from the fourth millennium to the 14th century AD in Egypt (Lucas and Harris 1962: 155). The Middle Kingdom seems to be the most experimental period of faience production, with the emergence of a high level of skill in the production process, and a high quality of glaze (Nicholson and Peltenburg 2000: 181). Faience during this time period was decorated with black paint and cementation glaze for the first time. It was during the Second Intermediate Period that faience changed in production methods, perhaps due to the change in governmental rule (Bard 1999: 54). In the New Kingdom faience was affected by the introduction of glass (probably made in the same workshops), which led to an increase in the colours used (Boyce 1989: 161, Vandiver 1998: 122-123). This period marks the peak of innovation and accomplishment for faience production.

Faience was very important to Egyptians, across every gender, age group, and socioeconomic level (Patch 1998: 42). The most prolific finds have all been in royal tombs, which suggests that this material was valued in itself, rather than simply

being regarded as a cheap imitation of gemstones (Nicholson 2007: 133, Tite and Shortland 2008: 57). On the other hand, relatively little textual data concerning faience has survived and no recipe is known, perhaps as a result of its assumed magical properties (Friedman 1998: 17). The colour, brightness, and shiny surface of faience appear to have been the principal qualities that made the material important to Egyptians (Tite *et al.* 2002: 585). The colour is possibly significant because it symbolises fertility, nature, good health, and protection from evil.

The earliest known faience objects in Egypt are beads, and beads themselves are one of the most common archaeological finds throughout the world and especially in Egypt and the Near East (Aldred 1971: 115). They survive well in the archaeological record because of the durable material they are produced with and their small size (Dubin 2006: 21). Beads are found either placed on purpose in the mortuary context, or casually lost in the settlement context. Beads are the first human form of decoration and artistic expression that have survived (Diamanti 2003: 10). Beads date back to over 60,000 years, and were mostly made of organic material (Sciama 2001: 1, Diamanti 2003: 8). The first beads found in Egypt date back to 12,000 years ago, and faience is the most common material used to make them (Lucas and Harris 1962: 7). Egypt's greatest contribution to jewellery is the quantity and inventive use of beads (Aldred 1971: 115).

Chapter 3

Background: Abydos From Excavation to Museum

3.1 Abydos

Situated in Upper Egypt at a mouth of a Wadi 95 kilometres north of Luxor is the site of Abydos (see Figure 3.1) (Helck 1975: 28, Richards 2005: 129). The entrance to the Wadi is on a route leading to the Western Desert and the Oasis of Dakhleh, allowing for trade along a canal connecting the site to the river Nile (Redford 1992: 14). Well known for its vast cemetery, there is also an associated settlement that is not as well researched.

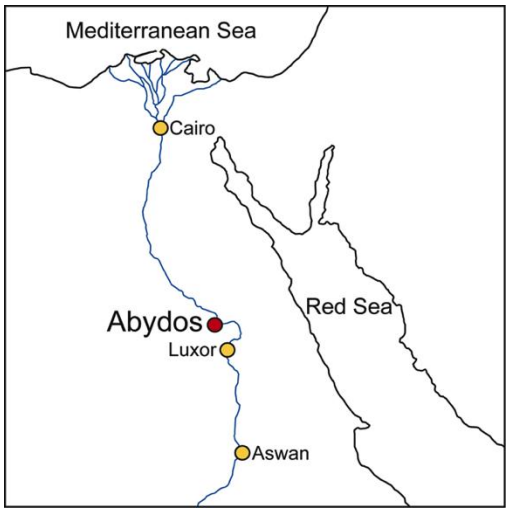


Figure 3.1: Abydos's relative location in Egypt in relation to Cairo, Luxor, and Aswan.

The settlement of ancient Abydos (Kom es-Sultan) was inhabited from the Predynastic to the Late Period (Bard 1999: 97-99, Helck 1975: 29, Shaw 2000: 64). Like most towns in Egypt, the ancient settlement was situated between the desert and the alluvium in order to avoid building on the vital agricultural land. The town was possibly positioned on a large mound 12 metres high (Helck 1975: 29). To the north and east the ancient town is bounded by, and probably covered by, the modern village of Beni Mansur (Bard 1999: 97). The town was bordered on the southwest by the low desert (the North Cemetery), which was utilised for a series of royal cult buildings dated to the Middle and New Kingdom, two of which are still preserved. These buildings are part of the complexes of Senusret III of the 12th Dynasty and Ahmose of the 18th Dynasty (Bard 1999: 160). Petrie, with the support

of the Egypt Exploration Fund (EEF), mapped and excavated these complexes between 1899 and 1902, at which point some of the surface features were still visible (Bard 1999: 106, Helck 1975: 30, Petrie 1900, Petrie 1920). Currently excavations are still being undertaken at the settlement site by a joint team from the University of Pennsylvania and Yale University Institute of Fine Arts in order to expand upon our understanding of the site and by the Toronto Votive Zone Project (Wagner 2012).

Abydos was chosen for this study specifically because of its notoriety as the largest and most continuously used cemetery in Egypt, providing faience material from every relevant time period (Drower 1995: 255-256). This site has been continually inhabited since 4800 BC and was the burial ground for the kings of the early dynasties (Snape 2011: 121). The main reason for Abydos' long use is its deep-seated religious importance, which started in the early dynasties and eventually reached its peak when the site became associated with the cult of Osiris and regarded as the burial place of the god (Snape 2011: 120, Taylor 2001: 27, and Richards 2005: 129).

There are several cemeteries at Abydos, which are divided up by the natural depressions in the sandy-gravel terraces bordered by the 'high desert' (Helck 1975: 34, Snape 1986: 1). The cemeteries were initially located, named, and described by Mariette (1880). These names were based on their location in the greater Abydos landscape. The cemetery located to the north-west was named/referred to as the 'North Cemetery', whereas the cemetery to the south-east, was referred to as the 'Middle Cemetery' and 'South Cemetery' (Figure 3.2) (Helck 1975: 34).

The North Cemetery, which has been utilised from the First Intermediate Period to the present (Bestock 2009: 42), was the main burial area for non-royal personages from the Middle Kingdom to the Late Period. This is the largest known cemetery for the middle class non-elites in Egypt. During the New Kingdom all social classes used the area for burial (Bard 1999: 95). This constant use of a relatively small area has caused some difficulty for archaeologists in dating the site, because of the reuse of space over and over again.

Due to the geology of the area, the most common types of tomb were the shaft and chamber style, normally situated in groups (Helck 1975: 35, Metcalf and Huntington 1991: 146). These tombs were often reused and there was no pattern to how the cemeteries were arranged as the result of constant use over vast amounts of time. Even the wealth of the individual did not affect the location of their burial (Snape 2011: 134). There are other theories about how the cemeteries were formed. John Garstang believed that with the increase of usage over time the

cemetery spread further to the west (Garstang 1901). However, the current hypothesis favoured by most researchers is that the tombs were located in association with the Osiris cult and essentially aligned with the river and the rising and setting of the sun (Snape 1986: 88).

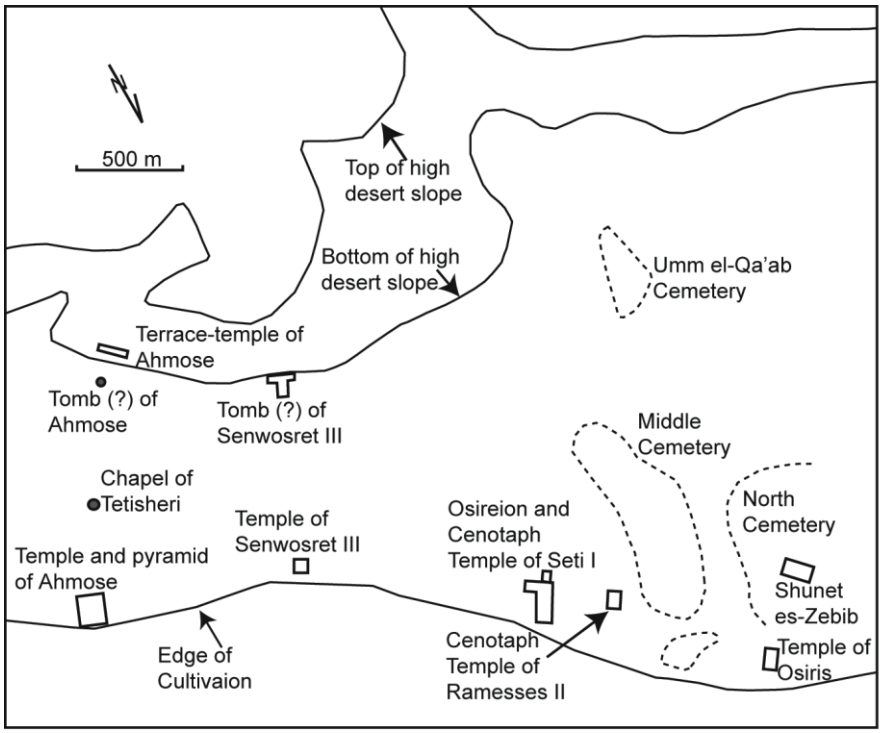


Figure 3.2: Location of the cemeteries at Abydos (adapted from Snape 2011: 27).

3.1.1 Abydos: A Chronological Summary

From the beginning of the Egyptian dynasties, Abydos played a vital role. The site has been studied because of its continued usage throughout Egypt's history, and its importance due to the early rulers of the first two dynasties being buried there, and the Osiris cult being associated with the site (Snape 2011: 120). However, the other significant appeal of Abydos is the burial of non-elites, non-locals, and the 'new' middle classes (middle management government administrators), which are rarely observed in other locations in Egypt (Bard 1999: 96). This section will present a summary of the history of Abydos chronologically.

During the period from the Predynastic to the Old Kingdom, Abydos was considered to be an important regional 'mini kingdom' (Snape 2011: 24-25). It was important for the formative years of the Egyptian government, which led to the Early Dynastic kings being buried there (Bard 1999: 28, Helck 1975: 28, Taylor 2001: 27). The rulers of the 1st Dynasty and two of the 2nd Dynasty were buried at Abydos, in the exclusive Umm el-Qa'ab cemetery (Bard 1999: 93, Snape 2011: 13, 25).

However, it is possible that there was no administration located at Abydos, and that they had their bodies sent to Abydos for burial (Helck 1975: 31).

At the beginning of the Middle Kingdom (2055-1650 BC), the whole of Egypt was reunited under one king and government (Callender 2000: 137, Richards 2005: 1). This new government started to grant private individuals access to restricted burial grounds such as Abydos, which appears to have been reserved for the royal and elite classes during the Predynastic and Old Kingdom periods (Bard 1999: 95). Due to the increase in private individuals' interest in Abydos, and the Osiris cult, there was an explosion in the number of private tombs, stelae, and chapels, all commissioned and paid for by the new 'middle class' of middle ranking administrators (Taylor 2001: 183).

As the result of the presence of the Osiris cult at Abydos, there was an increase in people living at, or making pilgrimages to, the site. Consequently, the cemeteries came to serve a larger, not just local, community (Helck 1975: 28-32), making Abydos the largest 'votive zone' and cemetery town of the Middle Kingdom (Snape 1986: 98, Callender 2000: 168, Richards 2005: 39). This suggests that, during the Middle Kingdom, Egypt was a safe place with a secure government that allowed pilgrims to travel from all over the country (Bard 1999: 49, Callender 2000: 168).

The Middle Kingdom graves are more numerous around Abydos's Osiris temple in the North Cemetery. These graves were of two varieties; shaft or surface graves. The shaft graves are commonly found in groups of two or more and are usually in alignment with the Nile's northern direction. Other than this, the shaft graves were variable in every other way including size, shape, quantity of chambers, and depth (Bard 1999: 96). The surface graves were just that, shallow pits, which were randomly distributed around the larger shaft graves. These graves are also oriented to the river's north, although far less effort was required for their construction. However, some of these graves have produced the largest amounts of finds (Bard 1999: 96).

The importance of Abydos, together with the frequency of burials, continued after the Middle Kingdom (Richards 2005: 126). The stability of the Middle Kingdom broke down and eventually the country divided, indicating the commencement of the Second Intermediate Period (Bourriau 2003: 172). During this time, the mortuary cult of Egypt declined and almost halted in the 13th Dynasty (Bard 1999: 34). This meant that the mummification practices and amassing of mortuary materials, which include faience, decreased. However, in Abydos the site remained under Theban control, and shaft graves of the Middle Kingdom type continued to be used in the form of the

shaft variety typical of the Middle Kingdom (Snape 1986: 97). In fact Snape (1986: 137) concludes that one of the most complete mortuary assemblages found at Abydos was the Second Intermediate Period Tomb 1802 excavated by Henri Frankfort (Frankfort 1930: 219). This shows that Abydos was continuously used during a period when most other sites were not.

In the early 18th Dynasty, Ahmose built monuments at many sites throughout Egypt including at Abydos, due to its continued use as a major cult centre (Bryan 2003: 211). The use of Abydos for burial persisted in this time period and long afterwards. However, it was not on a par with the level of usage experienced during the Middle Kingdom. The construction of the tombs continued in the same way as before, utilising unused areas or reusing older tombs.

3.1.2 Excavations at Abydos

Auguste Mariette undertook the first official excavation at Abydos from 1858 to 1875 (Mariette 1880). These excavations were then followed by the work of Émile Amélineau (1889-1900) (Amélineau 1899, Amélineau 1916) and William Flinders Petrie (1900) (Petrie 1900, Petrie 1920). The work of Mariette and Amélineau was very disorganised, whereas Petrie introduced a more scientific methodology (relative to the typical standards of that period; see Richards 2005: 128). Petrie excavated for four years at Abydos (later returning for another year in 1922) centring his efforts mainly on the royal tombs and the Osiris Temple (Drower 1995: 271, Murray 1961: 10, Petrie 1900, Petrie 1920).

This is by no means an exhaustive list of those who have excavated at Abydos. There are many who have worked the site in an unofficial/illegal capacity, and their discoveries have never been recorded. The excavators above remain the most prominent and have shed the most light on the site. More recent excavations have taken place at the site since 1966 (Wegner 2012); this work set out to develop a more comprehensive understanding of the site in a modern and systematic way, as mentioned in Section 3.1 above (Bard 1999: 96).

3.2 John Garstang's Work at Abydos

John Garstang (1876-1956) was born in Blackburn, Lancashire. He studied mathematics at Jesus College, Oxford (Freeman in prep.). After graduating in 1889, he worked in Cemetery E (el-Arabah) at Abydos supported by Petrie's Egyptian Research Account from 1899-1900 (see Garstang 1901). He then returned to Abydos for his own excavations from 1906 to 1909, subsequently excavating at Beni Hassan (1902-03), Hierakonpolis (1904-1905), Nagada, Edfu and several other sites

in Egypt, Nubia, and eventually at other sites across the Near East (Snape 1986: 49).

During this long period of excavations in Egypt, Garstang was affiliated with the University of Liverpool and indeed helped to found the first Department of Archaeology in England (Freeman in prep.). He was initially Honorary Reader in Egyptian Archaeology (1902-07) and later Professor of Methods and Practice of Archaeology (1907-1941; see Bienkowski and Tooley 1995: 103). As the result of Garstang's affiliation with the University of Liverpool, many of his finds from Egypt are now in museum collections in the northwest of England.

The site of el-Arabah (Cemetery E) was only excavated for one year (1899-1900) and published by Garstang separately from Petrie's reports (Garstang 1901). It contained twenty 12th Dynasty graves and twenty-two 13th Dynasty ones (Garstang 1901, Richards 2005: 142). Garstang eventually believed el-Arabah to be representative of Abydos as a whole, encompassing all time periods of Egypt's history, and he recognised its importance as a religious and funerary centre (Garstang 1901: 1). This may well explain why Garstang returned to Abydos Cemetery E in 1906 and excavated there until 1909. Garstang was personally granted the concession this time, which consisted of part of the funerary landscape a half kilometre around the Shunet el-Zebib (See Figure 3.2). This included most of the North and Middle Cemeteries (Snape 1986: 51).

Garstang excavated hundreds of pit tombs and shaft graves (Richards 2005: 143), but much of the data from these excavations is missing, including most of the tomb cards, maps, and excavation plans (Snape 1986: 26-27). The remaining evidence can be found in Garstang's personal field notebooks. However these records are incomplete, with the 1906 season being recorded only up to the discovery of tomb 34, the second part of the 1907 season being recorded, and just a portion of the 1909 excavation notes surviving (Snape 1986: 27). No field notebooks for 1908 have been located, leaving this season very poorly documented (Snape 1986: 59). In addition, the notebooks themselves are all written in pencil and have proved quite difficult to read, therefore the only reliable/available evidence is provided by Garstang's monthly reports to the members of his excavation committee, the hundreds of glass photographic negatives, and the artefacts themselves (Snape 1986: 29).

During the early twentieth century, Egypt still allowed the removal of artefacts from the country by excavators and antiquities dealers. Once Garstang's Abydos artefacts were recorded, they were sorted and distributed to three different groups of people: the Egyptian Antiquities Department (who selected about half of

the finds), the excavator, and those who funded the excavation (i.e. museums, institutions, societies, or individuals). Garstang funded his excavations with the aid of a committee predominantly based in Liverpool and the northwest of England (Snape 2011: 5, Freeman in prep.). The amount of artefacts removed from Egypt by Garstang is astonishing and calls into question whether this was an excavation of intellectual interest or a commercial venture. Freeman (in prep.) comments that the artefacts were reduced to pounds and shillings in Garstang's notebooks. Garstang evaluated all of the artefacts and determined a monetary value for each. He then created a system for distributing the materials to his committee, museums, or as gifts. After this distribution the artefacts entered the wider world and circulated from private ownership to museums, and were on loan to museums in Liverpool.

There are complications when it comes to evaluating Garstang's finds due to the lack of information from the excavations (maps and notebooks), which leads to contextual problems. This is a matter that will only get worse over time as the quality of his notes deteriorate, leading to problems in determining the dates of the tombs. This in turn has created some difficulties for the analysis and interpretation of the faience material forming the basis of this thesis. Snape (1986) has compiled much of the archival information concerning artefacts from Garstang's excavations that remain in the Garstang Museum. His PhD research was specifically conducted to reconstruct Garstang's excavations at Abydos and develop an understanding of the associations between the burials and the artefacts. Most importantly, with regard to the faience material used for the present thesis, Snape developed a typology based on the ceramic assemblages of the tombs, which will be used here to date the bead assemblages found within the tombs. It is not the most accurate of methods, but is commonly used in archaeology and, due to the lack of information, it is the only way to procure a date for this material.

The question may be asked: why use the material from Garstang's excavations as the primary data for this thesis given the problems outlined above? There are several reasons, one of which is access to the artefacts. Faience material and other artefacts can no longer be removed from Egypt, and obtaining access to scientific equipment within Egypt is virtually impossible. Therefore it is common to study material that has already been removed from Egypt (legally) in other locations. Due to Garstang's connections to Liverpool many of the finds are located at the University of Liverpool's Garstang Museum, Bolton Museum, and Manchester Museum. This provides a unique opportunity for access to a conveniently located collection of excavated, provenanced material.

The second significant reason for studying Garstang's material from Abydos is that it comes from mortuary assemblages. This material is often found in a closed context, with textual information that often aids in dating the material. Also, because of the locations of the tombs and arid conditions, the material tends to be better preserved than at settlement sites, however in the case of faience the material survives very well at both types of sites (Richards 2005: 52). As Snape (2011: 26) states, "the reason that the study of ancient Egyptian tombs and their contents is so important is that they provide a wealth of primary evidence which can be used in different ways by archaeologists with very different research agendas". This can be anything from developing theories on ideologies of power, status, and wealth represented in the material culture (Richards 2005: 59), to developing typologies of the materials for dating purposes, or textual evidence left on the walls of the tombs themselves.

All of the tombs used for this research were selected to represent their time periods based on their assemblage's accessibility, the presence of faience beads, and datable material. Therefore the first action was the selection of the tombs, which began with reviewing Garstang's reports and Snape (1986) in order to determine which tombs had faience beads. After determining the potential tombs for sampling a review of the Garstang Museum (University of Liverpool), Manchester Museum, and Bolton Museum catalogues was undertaken to ensure the presence of the beads within the museums collections and to negate any incomplete or missing assemblages. The tombs selected for sampling had datable material within the assemblage as well as faience beads in reasonable quantities. The next step was to apply for access and permission to perform destructive analysis of the beads in these tombs, which was granted by all three museums. Therefore, out of all of the assemblages in the Garstang Museum, Manchester Museum, and Bolton Museum from Garstang's excavations at Abydos, every tomb that could be ascribed a time period that fell within this research's remit that had datable material and faience beads was sampled.

The information provided in the upcoming sections has been compiled from Garstang's own notations and/or from Snape (1986) compilation of Garstang's research and is presented here with Snape's permission. Each tomb will be presented in chronological order, then by the museum they are from. The known construction and location will be presented along with the material found within. Then the item(s) used to date the tomb will be shown. All of the materials are assigned accession numbers as follows: the vast majority start with an E and then the number for the Garstang Museum (example E 2380), MAN for Manchester

Museum, and 54.00.75 or 54.00.79 for Bolton Museum. These numbers will be used, rather than the tomb numbers, in order to identify the beads analysed. This will limit confusion as there is only one tomb number for each accession number, while there can be many accession number per tomb.

3.3 Middle Kingdom Tombs

3.3.1 The Garstang Museum

The Garstang Museum was the source for the vast majority of the material analysed in this research. When the museum was founded, it consisted of a loan collection from Garstang and his committee members to the university for teaching purposes (Freeman in prep.). The museum has been moved four times, over the past century. One of the original locations for the museum was bombed during World War II and, whilst much of the collection had been removed beforehand for safekeeping, most of what remained was destroyed (Bienkowski and Tooley 1995: 105). The Garstang Museum is currently located on the ground floor of 14 Abercromby Square, in the Department of Archaeology, Classics, and Egyptology. The Garstang Museum houses all of the notebooks, drawings, reports, photographs, over 800 glass negatives, pottery, and fragmentary field notes from Garstang's excavations at Abydos.

3.3.1.1 TOMB 9 A'06 (E 9384)

Tomb 9 A'06 was excavated by Garstang in the 1906 field season. The location of this tomb is now unknown, although it was stated that there was a small mastaba located to the south of it. The tomb consists of three pits: the Central, Eastern, and Western pit. The contents of these three pits are divided based on what was within them. The Central pit contained two ivory hands, a few glazed dog amulets, glazed beads, and fragments of a *kohl* pot. An incised rod of turquoise faience (Figure 3.3, Artefact 11) and a number of small blue beads were found in the Eastern pit. The Western pit contained a blue anhydrite vessel (Figure 3.3, Artefact 1), an ivory lid of a quadripartite vessel (Figure 3.3, Artefact 2), a stela, a copper mirror, and beads of carnelian, jasper and other precious stones. There were also faience beads of varying colours (Figure 3.3, Artefact 3) (accession number E 9384). These are the beads sampled for analysis in this research. The Western pit was dated to the Middle Kingdom based on the anhydrite vessel (Figure 3.3, Artefact 1), which has a collar characteristic of this period (Snape 1986).

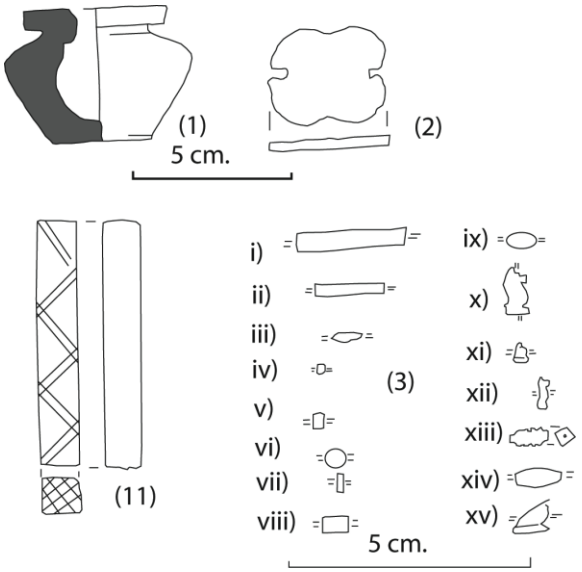


Figure 3.3: Some of the artefacts found in Tomb 9 A'06 (adapted from Snape 1986).

3.3.1.2 TOMB 330 A'07 (E 2345)

Tomb 330 A'07 is a pit tomb, excavated in 1907, and the location of this tomb is unknown. The tomb contents included a ceramic vessel with brown fabric and no slip (Figure 3.4, Artefact 1), beads of various types including faience (Figure 3.4, Artefact 2) (E 2345), two scarabs (Figure 3.4, Artefact 3), copper scraps (Figure 3.4, Artefact 4), a bronze mirror, a fragment of a limestone stela which was found near by, and four alabaster vases (two of which are kohl pots) (Snape 1986). The tomb is dated to the Middle Kingdom based upon the scarabs (Artefact 3) and the bronze mirror (not pictured), which are diagnostic for this period.

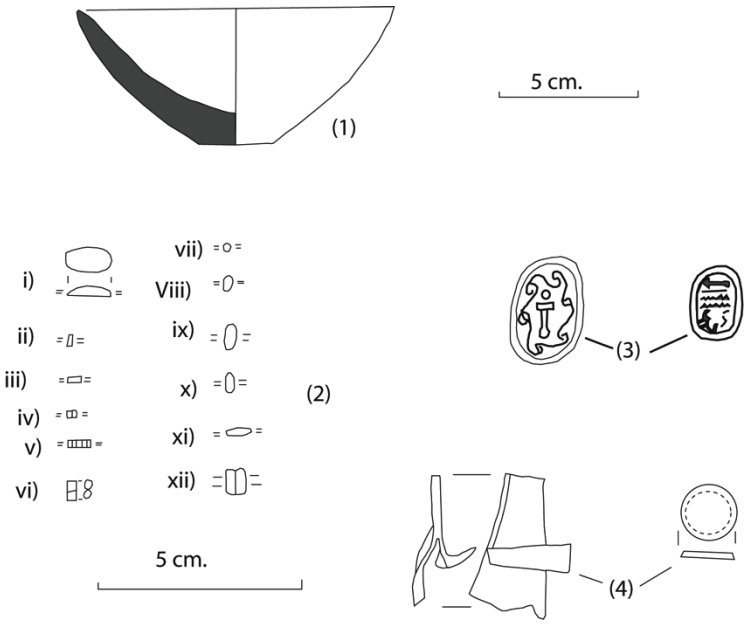


Figure 3.4: Artefacts from Tomb 330 A'07 (adapted from Snape 1986).

3.3.1.3 TOMB 359 A'07 (E 2379)

The location and construction of Tomb 359 A'07 is unknown. The only thing that is known is that the tomb was excavated in 1907. The artefacts found within the tomb included a ceramic vessel with reddish-brown fabric and no slip (Figure 3.5, Artefact 1), and a ceramic vessel with brown fabric and red slip (Figure 3.5, Artefact 2). Other items found within the tomb include an alabaster vessel (Figure 3.5, Artefact 3), fragments of blue faience inlay (Figure 3.5, Artefact 4), a wooden vessel lid (Figure 3.5, Artefact 5), and faience beads of various colours (Figure 3.5, Artefact 6) (E 2379). This tomb was dated to the Middle Kingdom based on the alabaster vessel (Figure 3.5, Artefact 3). This vessel is considered to be a tripartite vessel, which was constructed in three pieces and is characteristic of the Middle Kingdom.

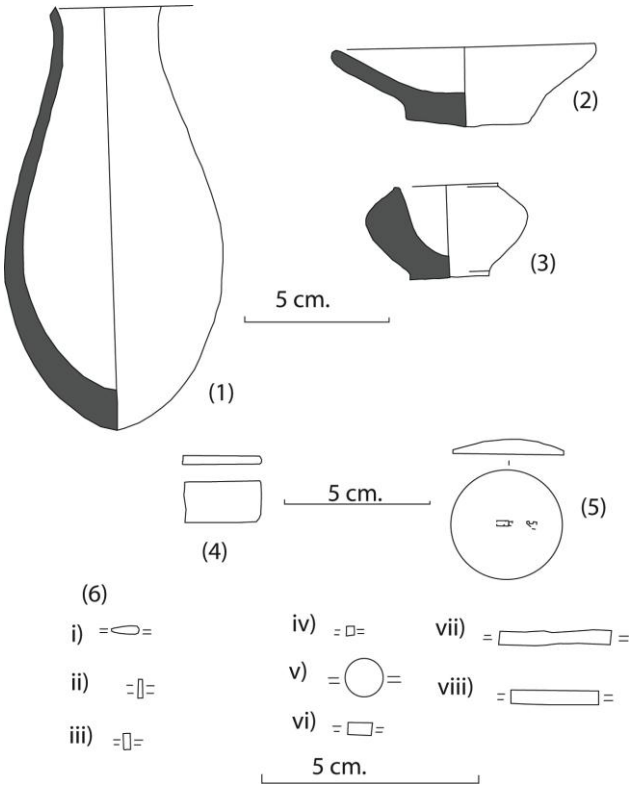


Figure 3.5: A selection of Tomb 359 A'07 artefacts (adapted from Snape 1986).

3.3.1.4 TOMB 427 A'07 (E 2130)

This tomb was excavated in 1907, and the location and construction of the tomb is unknown. The tomb contained a number of ceramics of varying types, including a ceramic vessel, with reddish yellow fabric which is self-slipped (Figure 3.6, Artefact 1), another ceramic vessel of reddish yellow fabric with a reddish brown slip (Figure 3.6, Artefact 2), and several ceramic vessels with brown fabric and no

slip (Figure 3.6, Artefacts 3-6). Artefact 7 is a ceramic vessel with brown fabric and patches of red slip. Artefact 8 (Figure 3.6) is a ceramic vessel with reddish-yellow fabric, red slip, and a white painted band. This artefact is diagnostic of the Middle Kingdom and has been used to date this assemblage. The tomb also contains several varieties of faience beads (Figure 3.6, Artefact 9) (E2130), which were sampled for this research. Other items that are recorded as being part of this tomb assemblage but were not located by Snape (1986) include red pottery dishes with incised patterns, green glazed scarabs, the lid of a dark stone kohl pot, fragments of an alabaster vase, and a few green glazed balls.

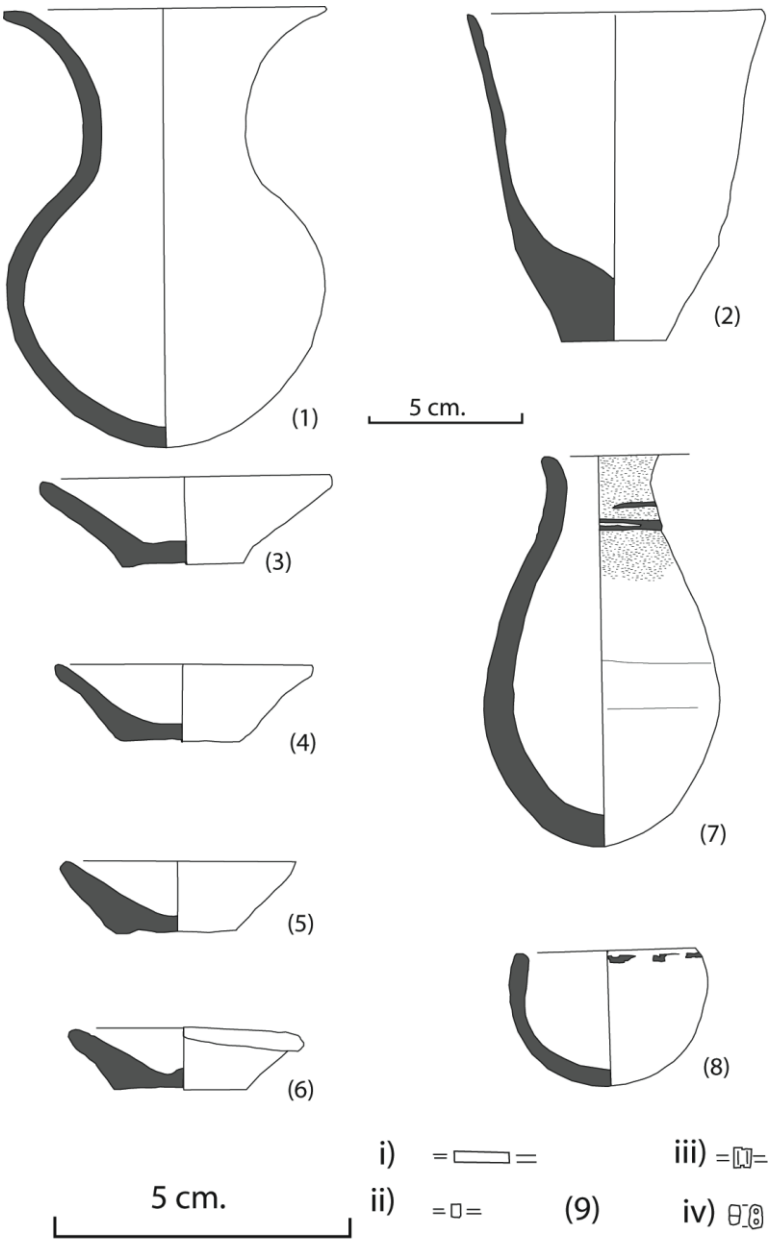


Figure 3.6: Tomb 427 A'07 artefacts (adapted from Snape 1986).

3.3.1.5 TOMB 475 A'08 (E 2435)

The construction and location of this tomb is unknown. The tomb was excavated in 1908, and Garstang's notebooks are missing from this year (see above), which could explain the lack of information. The contents of this tomb consisted of a limestone head from a statuette (Figure 3.7, Artefact 1), a serpentine vessel with lid (Figure 3.7, Artefact 2), a metal (possibly silver) ring (Figure 3.7, Artefact 3), and fragments of bone inlay (Artefact 4). There were also many different beads of carnelian, dark blue glass, amethyst and faience (Figure 3.7, Artefact 5) (E 2435). This tomb included three blue faience scaraboid beads (Artefact 6), wooden rectangular pieces (Artefact 7), and two wooden pontils (Artefact 8). Tomb 475 A'08 was dated to the Middle Kingdom based on the limestone statuette head, which has the common tripartite style head dress (Figure 3.7, Artefact 1).

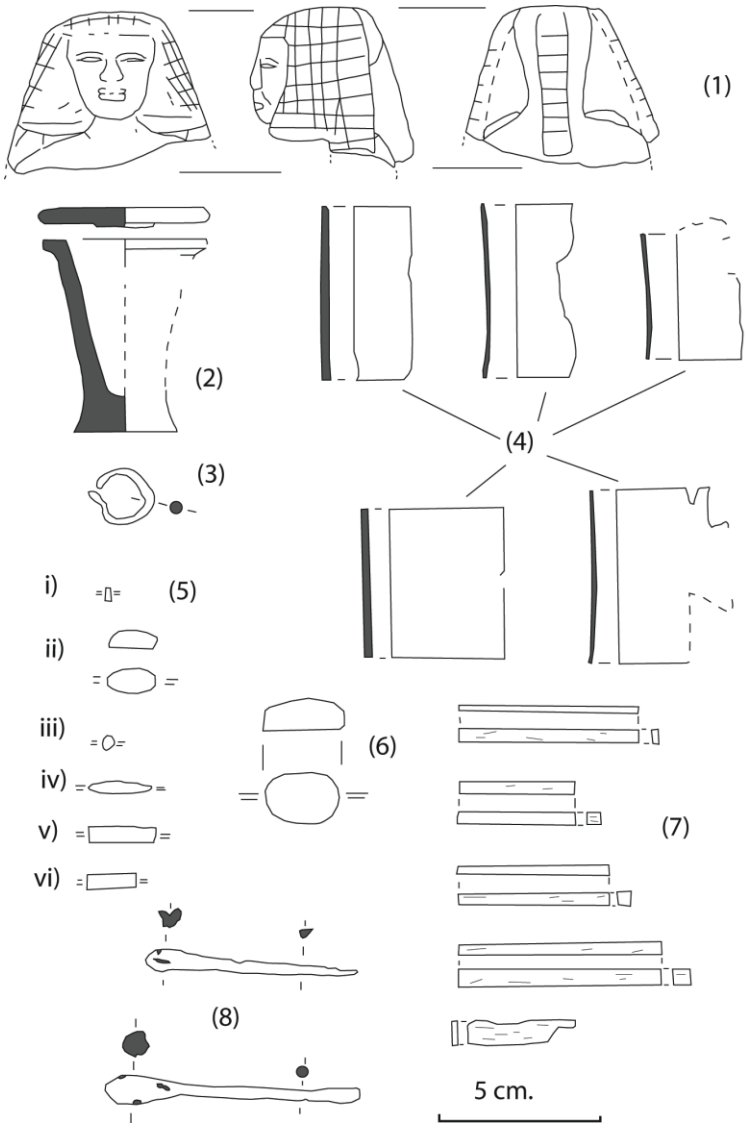


Figure 3.7: Artefacts found in Tomb 475 A'08 (adapted from Snape 1986).

3.3.1.6 TOMB 498 A'08 (E 2383)

This tomb was originally discussed and analysed in the pilot project for this research (Hammerle 2008). It is presented here with the greater bulk of the material now analysed. This tomb is similar to tomb 475 A'08 in that it was excavated in the 1908 field season and therefore the data is very limited. The construction and location of this tomb is unknown. The artefacts were found in it are predominantly beads of yellow steatite, carnelian, lapis lazuli, and green, black, and blue faience (E 2383). The other item in the assemblage is a blue faience hippopotamus decorated with dark purple paint, which was used to date the tomb to the Middle Kingdom as it is typical of this period (Figure 3.8) (Nicholson 1993: 23).

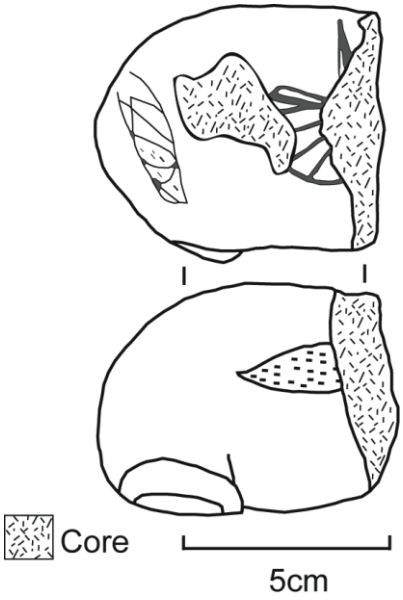


Figure 3.8: Hippopotamus fragment from Tomb 498 A'08 (adapted from Snape 1986).

3.3.2 Bolton Museum

The difference between the Bolton collection and those of the Manchester and Garstang Museums is that this material comes from the el-Arabah excavations at Abydos mentioned in Section 3.2.1. Garstang published the results of this excavation (Garstang 1901), so this publication will form the primary source for this section. However, the information he provides is both fragmentary, and at times unreliable, as there are question marks on the labels associated with the artefacts in this collection.

3.3.2.1 TOMB 105 (54.00.75)

Tomb 105 is a pit tomb that was dated to the Middle Kingdom by Garstang (1901: 40), based on the finds found within. These finds included a statuette, alabaster vessels, and groups of beads (54.00.75) (Figure 3.9). The 'globular beads of green glaze' put together as a necklace at the top of Figure 3.9 suggested to Garstang that the material was from the 12th Dynasty (Garstang 1901: 5 and 30). However, Garstang recognised that the tomb was disturbed, so this material will be treated with care.

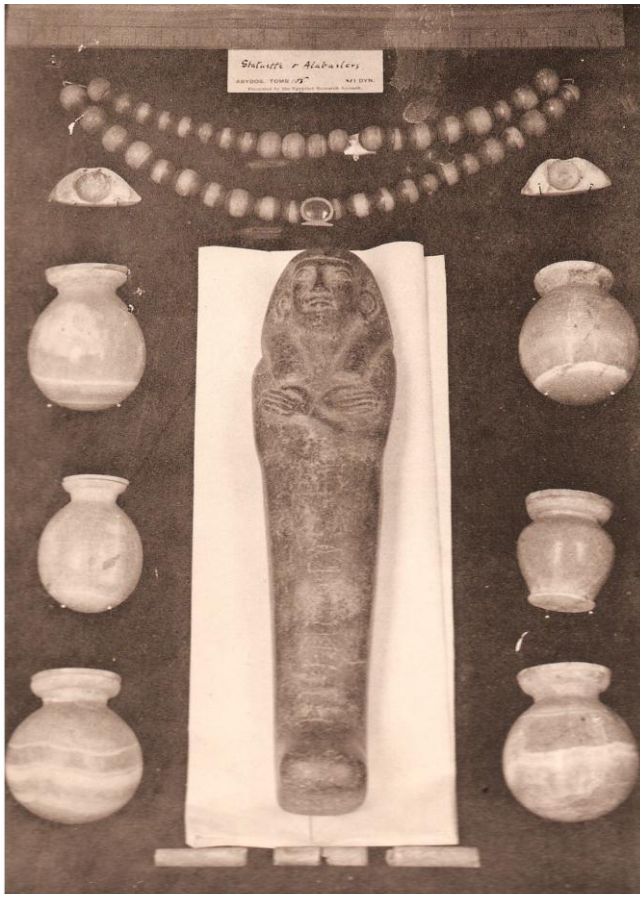


Figure 3.9: Artefacts from Tomb 105 (photograph from Garstang 1901).

3.3.2.2 TOMB 330 (54.00.79 and 54.00.79?)

Tomb 330 is another disturbed pit-tomb with a *mastaba* located nearby (Garstang 1901: 9). Two stelae found near to the tomb have been used to date the beads (54.00.79 and 54.00.79?). The stele of Neteru-refu is dated to the 12th or 13th Dynasty (Garstang 1901: 41). Nub's stele found nearby is dated to the New Kingdom, suggesting a disturbed context for the material. Another confusing aspect of this tomb is the fact that there are two bead assemblages (albeit, very similar to each other) with the same accession number, yet one has a question mark behind it.

Both bead assemblages are also very similar to those of 54.00.74 and therefore all were sampled for analysis.

3.4 Second Intermediate Period Tomb

3.4.1 The Garstang Museum

3.4.1.1 TOMB 458 A'08 (E 2385)

Once again the limited data from the 1908 field season has provided no information on the construction or location of Tomb 458 A'08. This tomb contained several beads of green and blue faience (Figure 3.10, Artefact 1) along with a scarab that is stylistically indicative of the Second Intermediate Period. This was the only tomb that could be dated to this period that had faience beads.

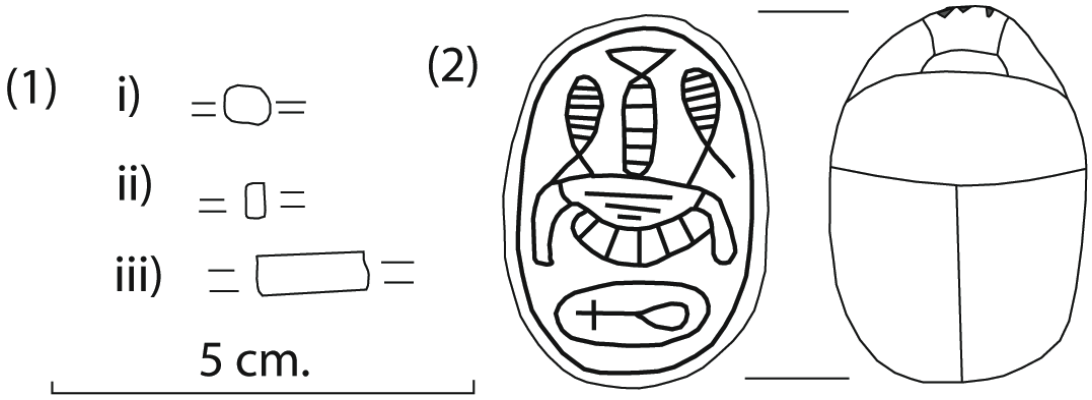


Figure 3.10: Tomb 458 A'08 beads and scarabs (adapted from Snape 1986).

3.5 New Kingdom Tombs

3.5.1 The Garstang Museum

3.5.1.1 TOMB 492 A'08 (E 2380)

The location and construction of this tomb are unknown, and the contents were used to date the material. There were a variety of faience beads found within the tomb along with gold beads, and stone beads (E 2380) (Figure 3.11, Artefact 1). The artefact used to date the tomb is the *Wd3t* amulet in dark stone, which can be typologically dated to the New Kingdom (Figure 3.11, Artefact 2). Other items found within the tomb include fragments of a clay seal impression, and ceramics of various types (not depicted). Out of these ceramic types, number 55 is the significant one to note. Snape (1986) created a typology of the ceramics from Abydos and concluded that type 55 is distinctive of the New Kingdom.

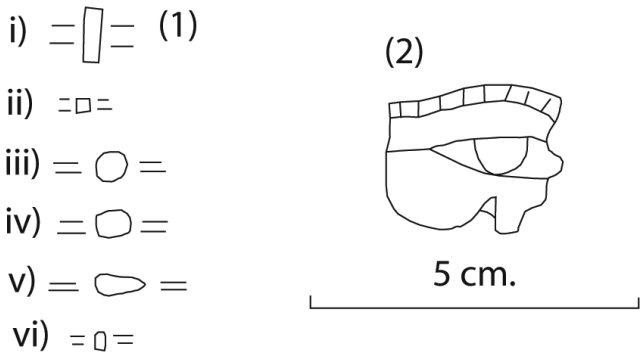


Figure 3.11: Artefacts from Tomb 492 A'08 (adapted from Snape 1986).

3.5.1.2 TOMB 525 A'08 (E 2384)

The location and construction of this tomb are once again unknown. The contents are the only information available and even then they are few in number. The assemblage includes a bone pin (Figure 3.12, Artefact 1). There were also a large variety of faience beads of various colours found within the tomb (E 2384) (Figure 3.12, Artefact 2). Other faience items are also included in the assemblage, such as the head of a blue faience Nephthys amulet (Figure 3.12, Artefact 3). The material in this tomb is dated to the New Kingdom based on the presence of the ceramic type 55. Also, Artefact 3 is diagnostic of the New Kingdom.

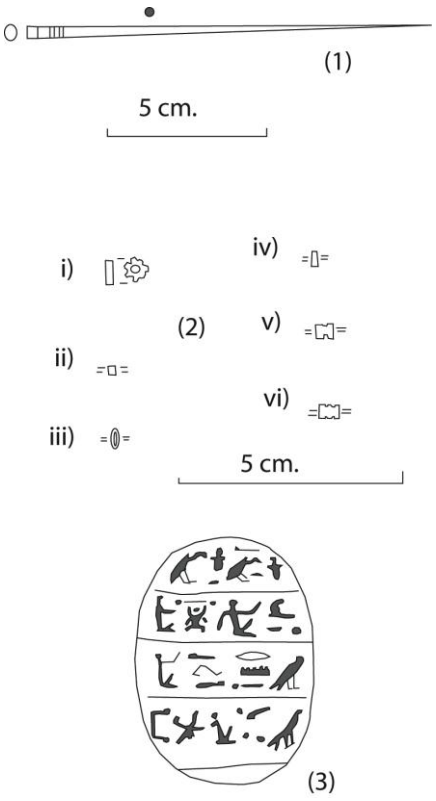


Figure 3.12: A few of the artefacts from Tomb 525 A'08 (adapted from Snape 1986).

3.5.1.3 TOMB 577 A'08 (E 2375)

Tomb 577 A'08 has limited information and the construction and location are unknown. The assemblage from this tomb consists of a ceramic vessel with pink fabric, slipped and burnished in dark red (Figure 3.13, Artefact 1). There are two types of beads found in this assemblage those made of mud (Figure 3.13, Artefact 2) and those made of faience and lapis lazuli (Figure 3.13, Artefact 3). Items not depicted here include a buff-fabric ceramic vessel with incised and painted decoration, a scarab, and bone inlay strips with incised circle and dot decoration. The other items not depicted are the ceramics, which have been utilised to date the material. Once again the main type of ceramic is 55, which has aided in dating this tomb to the New Kingdom (Snape 1986).

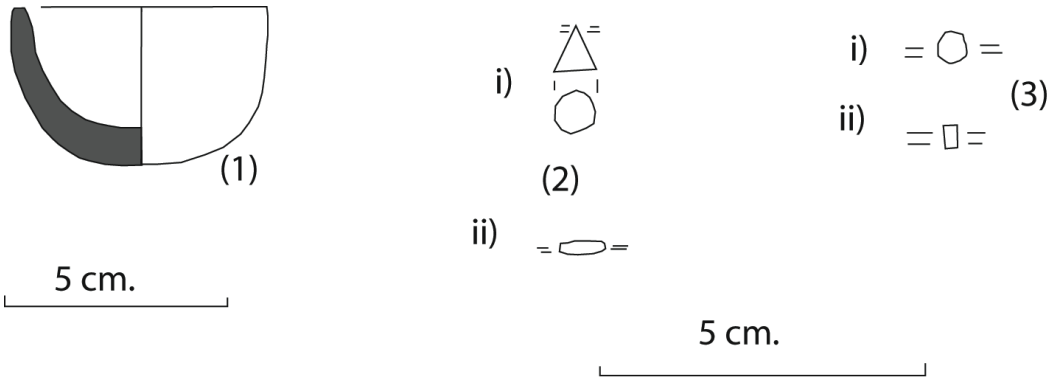


Figure 3.13: Tomb 577 A'08 artefacts (adapted from Snape 1986).

3.5.1.4 TOMB 649 A'08 (E 2389)

Once again the construction and location of this tomb are unknown and the material is the only remaining data available. The assemblage for this tomb contains several different types of beads including blue stone, lapis lazuli, and many different coloured faience beads (Figure 3.14, Artefact 1) (E 2389). Also contained in this tomb assemblage are three ivory inlay strips with incised dot and concentric circle decoration (Figure 3.14, Artefacts 2-4) and a blue glazed steatite scarab. This tomb is dated to the New Kingdom based on the ivory strips, which are indicative of the 18th Dynasty. The blue glazed steatite scarab confirms this date.

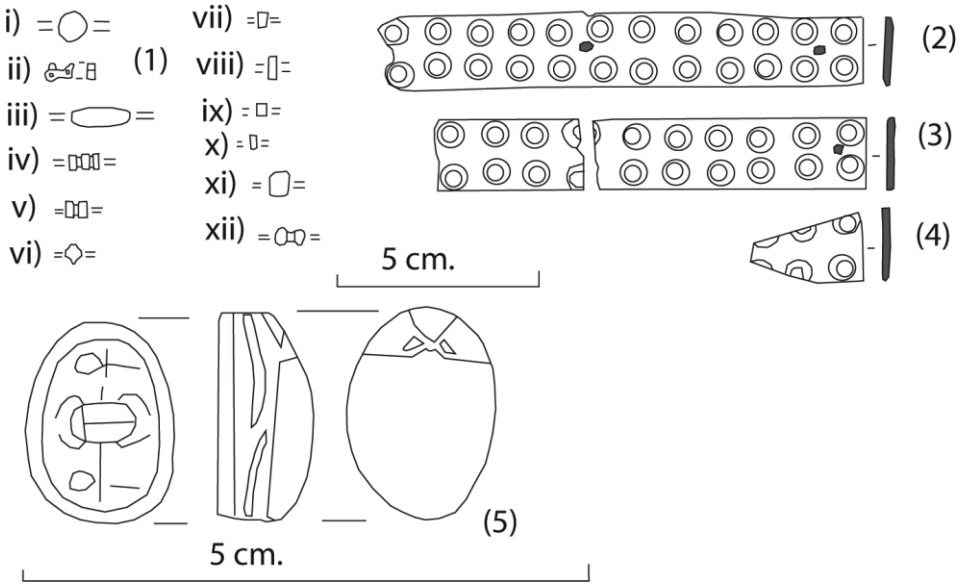


Figure 3.14: Tomb 649 A'08 beads, scarab, and ivory inlays (adapted from Snape 1986).

3.5.1.5 TOMB 942 A'09 (E 2344)

Tomb 942 was recorded with much more precision than Garstang gave to the tombs of the previous years. There are photographs, maps, and material remaining from this tomb's excavation. This could be because Tomb 942 belonged to a larger group of tombs (941-949 A'09) and these were some of the richest he discovered (Figure 3.15, Snape 1986). This tomb was also noted as being undisturbed. Tomb 942 is a vaulted multi chambered tomb dated to the mid 18th Dynasty, and may be Garstang's most securely dated New Kingdom tomb. The material found in this tomb includes imports such as Cypriot pottery, and a large variety of beads, which aid in dating the whole tomb (Figure 3.16).

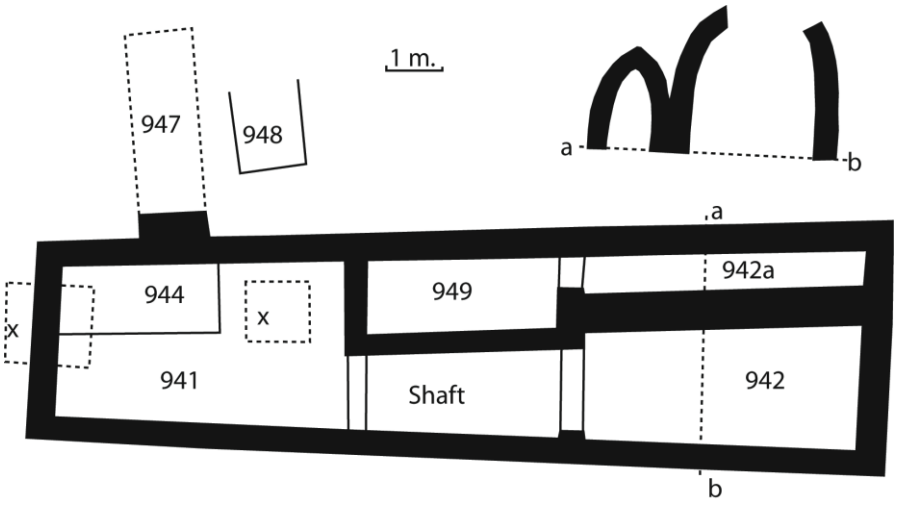


Figure 3.15: The chambers of the 18th Dynasty tomb (adapted from Snape 1986).

Figure 3.16: Artefacts from Tomb 941 to 949 A'09 (photograph from Snape 1986).

3.5.1.6 TOMB 541 A'08 (E 2377)

This tomb was part of the pilot study (Hammerle 2008) and has been included here to present all the information in one document. This tomb's construction and location are unknown. The contents of the tomb include ceramics, ivory clappers, bone, twelve links of copper, and beads. The beads include steatite, green stone, lapis lazuli and faience of various colours. The tomb has been dated to the New Kingdom by the imported material including a Cypriot 'spindle-bottle' (Figure 3.17, artefact 1) and by Artefact 2, which is a ceramic vessel characteristic of this period. Other artefacts that help to date this tomb are the ivory clappers (Figure 3.17, artefacts 9 and 10). This type of artefact is present in tomb assemblages before the New Kingdom.

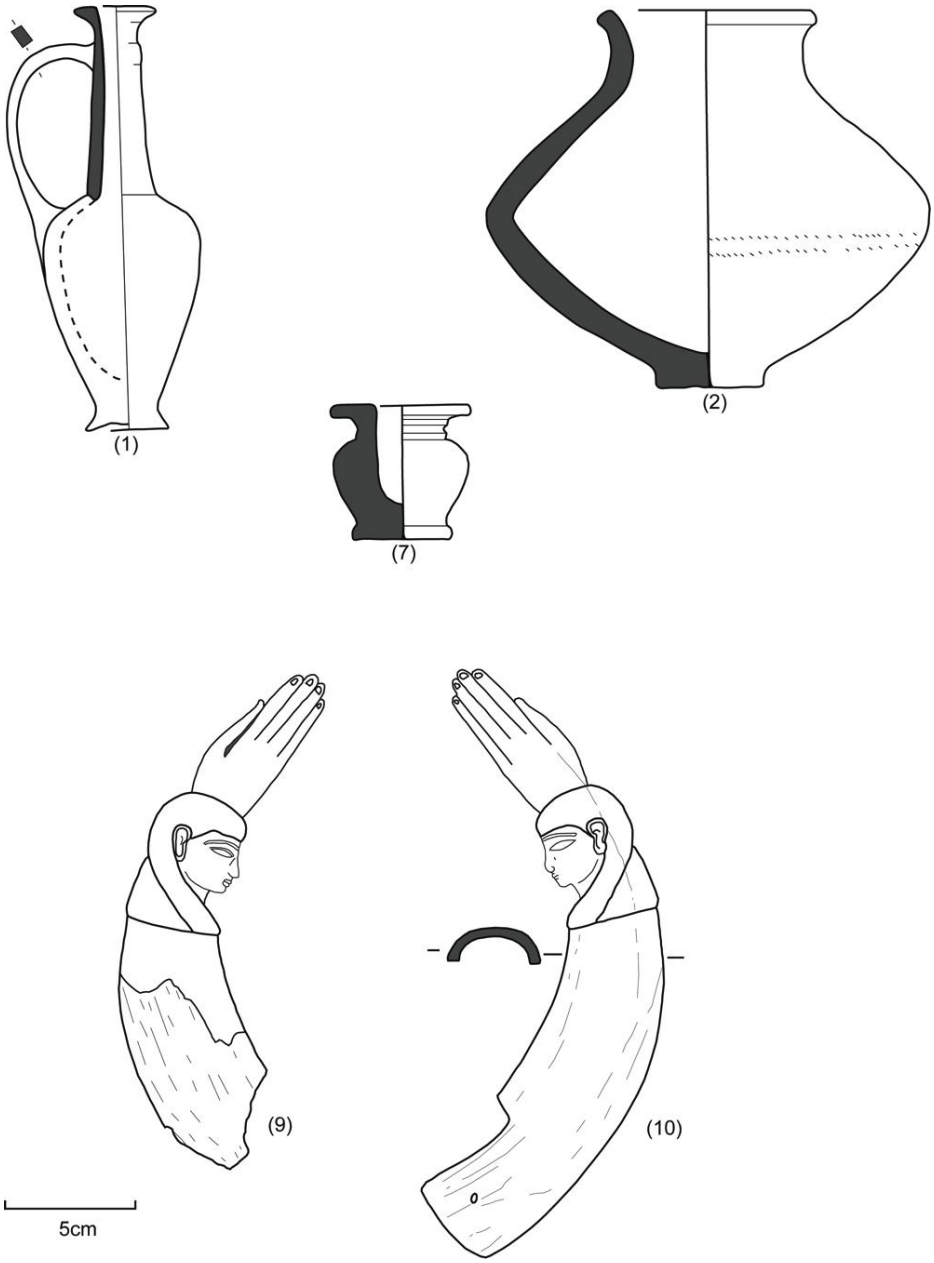


Figure 3.17: Tomb 541 A'08 datable finds (adapted from Snape 1986).

3.5.2 Manchester Museum

Manchester Museum was originally established as a natural history museum in 1835. An influx of archaeological material started around 1912, due to donations by local collectors. The museum expanded to the vast collection it is now, due to Garstang's distribution of the finds to wealthy industrialists around north-west England. Some of his material from Abydos is now housed in the Manchester Museum. The material in this collection was excavated at the same time as the Garstang Museum collections. Snape's (1986) dissertation included this material, and it will be presented below.

3.5.2.1 TOMB 18 A'06 (Man. 4075)

The location of Tomb 18 A'06 is the southern edge of the North Cemetery. The tomb itself consists of a group of rectangular shafts, however the number of chambers is unknown (Figure 3.18). When excavated, these shafts were treated as one, and it is unclear from which of the chambers the artefacts came. Therefore, they have been treated as one assemblage (Snape 1986: 195). The material from this excavation included large quantities of ceramic vessels, such as a base-ring juglet, and two imported Cypriot ceramics (Figure 3.19, Artefacts 3 and 4). These pots help to date the material to the New Kingdom's 18th Dynasty along with ceramic type 55, which is present in the assemblage. Other materials and artefact types in the assemblage include alabaster vessels, stone vessels, and a slate palette. Bone inlay strips, ivory bracelet fragments, and fragments of ivory are also present, which help to date the tomb (Figure 3.20, Artefacts 29 – 34). There is also faience material present in the form of rings, beads, and bowls. This tomb contains a large variety of material that is only partially covered here, to give a basic understanding of the quantity of the material. There is so much more in this assemblage that will not be displayed here, see Snape 1986 for further details.

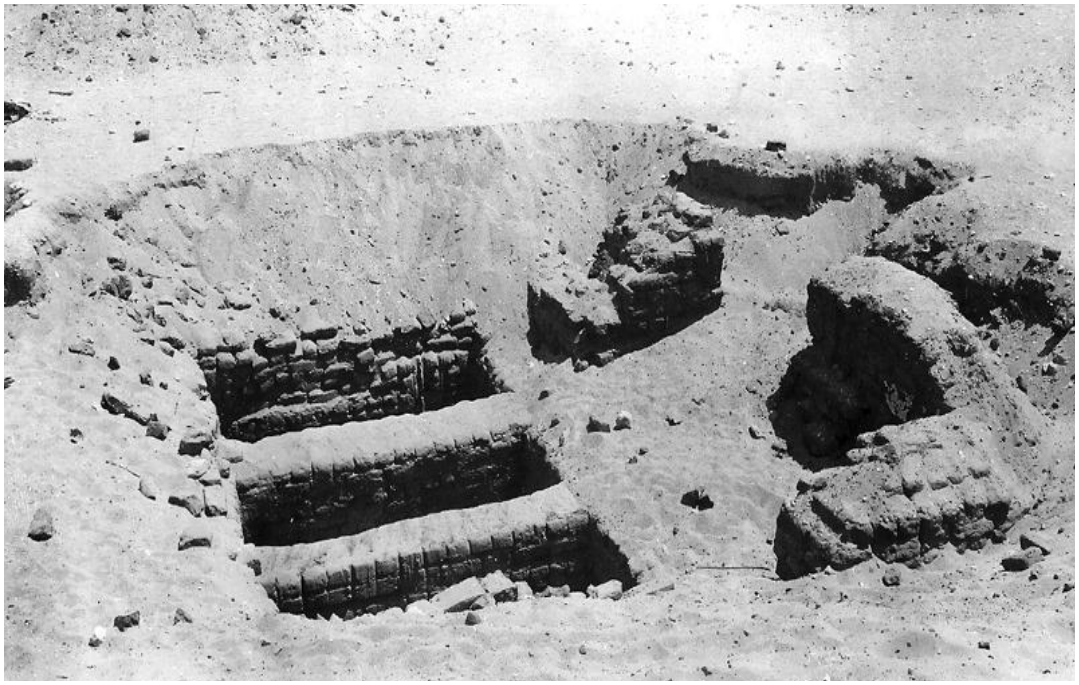


Figure 3.18: Tomb 18 A'06 shafts (photograph from Snape 1986).

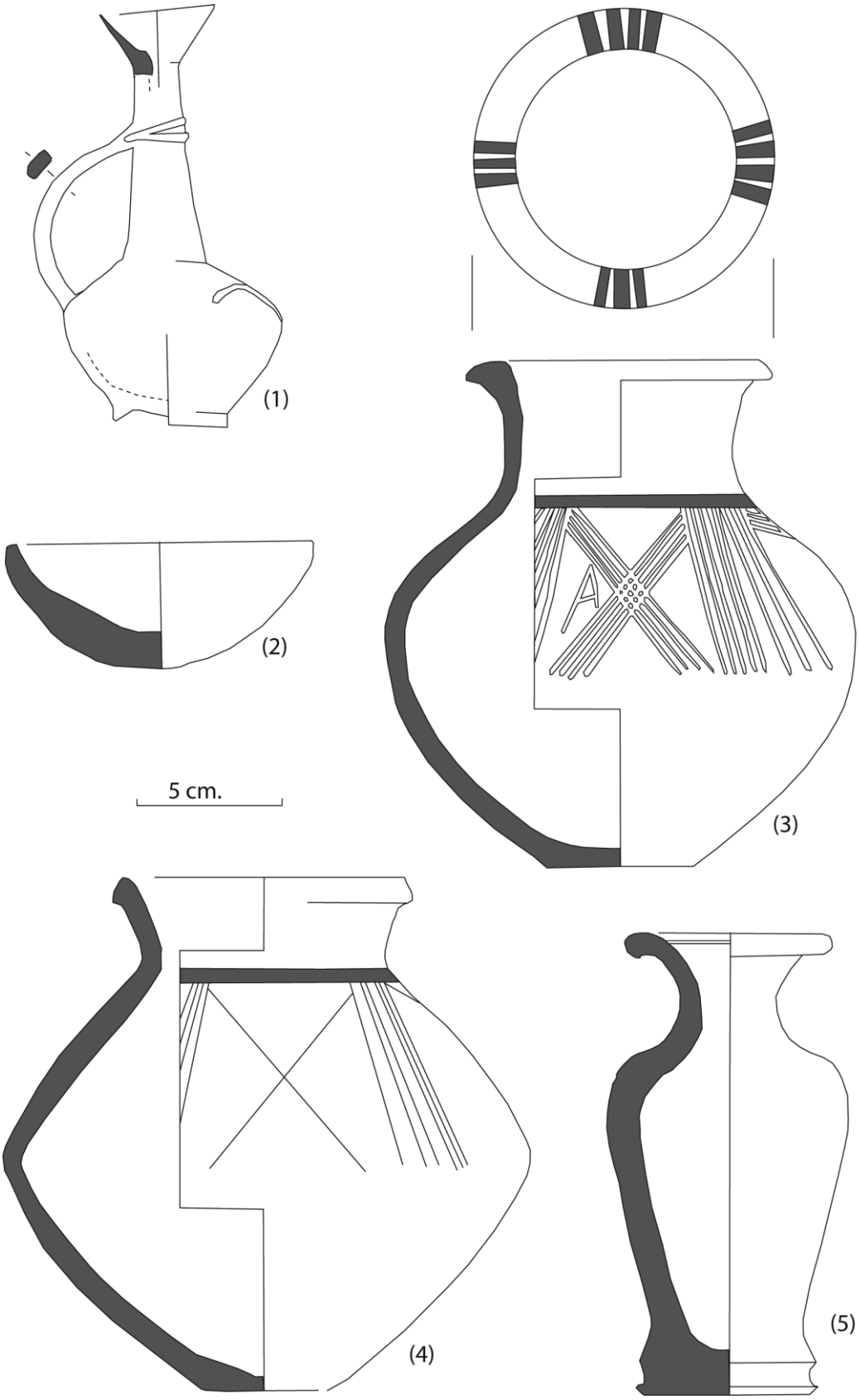


Figure 3.19: Artefacts 1 to 5 from Tomb 18 A’06 (adapted from Snape 1986).

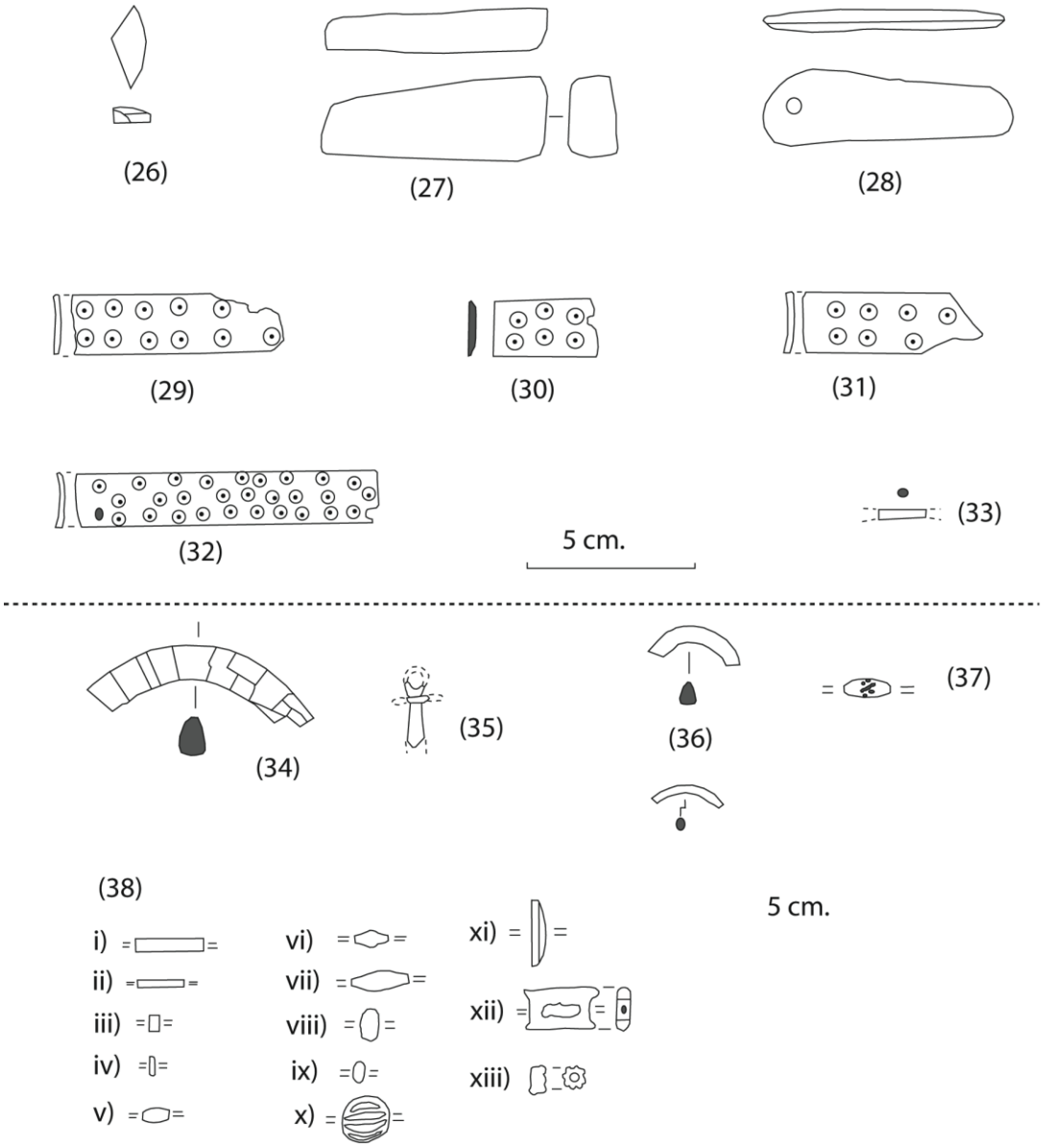


Figure 3.20: Artefacts 26 to 38 from Tomb 18 A'06 (adapted from Snape 1986).

3.6 Summary

This chapter has comprised a background discussion of Abydos in Upper Egypt as a settlement and cemetery site that has been used since the Predynastic well into the Late Period. It was chosen as a case study for this research because of its long history of usage and the scale of its cemeteries. The significance of Abydos changed over time from the Predynastic and the Old Kingdom, when it was used as a royal burial ground of the early dynastic Kings (Bard 1999: 95, Taylor 2001: 27, and Richards 2005: 129). In the Middle Kingdom, with its symbolic representation as the burial place for Osiris, pilgrims came from far and wide to leave their presence on the sacred landscape, scattering it with stelae and chapels (Snape 2011: 120,

Callender 2000: 168). This aided in creating the largest votive zone and cemetery of the Middle Kingdom (Taylor 2001: 183). Throughout the Second Intermediate Period most monumental mortuary practices in Egypt ceased, except in Abydos where it continued as before (Bard 1999: 34). In the New Kingdom all social classes used these burial grounds, leading to disturbed and random placements of tombs (Bryan 2003: 211).

Many important archaeologists including Mariette, Amelineau, Petrie, Garstang, and many more, continuing into the twentieth century, have excavated Abydos. They have excavated the settlement site and several of the cemeteries. The North Cemetery is considered to be the main one due to its size and its mixed population of non-elites, non-locals, and the middle classes of Egypt (Bestock 2009: 42). The most common types of tombs were those of the shaft and chamber variety or the surface (pit) variety (Helck 1975: 35, Metcalf and Huntington 1991: 146). The position of these tombs in the landscape was not based on wealth or social standing, but was chosen in relation to the position of the Osiris Cult's key locations (Snape 1986: 88).

Garstang excavated twice at Abydos, once under Petrie in 1899-1900, and then in 1906-1909 for his own excavations. During his first excavation he excavated and recorded 42 graves from the 12th and 13th Dynasties in a location he referred to as Cemetery E (part of the North and Middle Cemetery) (Richards 2005: 142). During Garstang's second stint at Abydos he excavated hundreds of graves from several different periods and of various types (Snape 1986). There is a general lack of information on the tombs he excavated, which is due to several reasons discussed in Section 3.2.3, but this has hopefully been addressed by the use of Snape's (1986) dissertation. Even though there is a lack of data, much can still be learned from the artefacts themselves.

Garstang's excavations at Abydos are of particular interest for this research due to the fact that all of the material analysed is from his excavations. The tombs used for this research were selected because they were representative of the periods of interest outlined in the research remit, the contents were accessible, and because they contained faience beads and datable material. The selection of the tombs began with reviewing Garstang's reports and Snape (1986) to determine which tombs had faience beads. Then the Garstang Museum, Manchester Museum, and Bolton Museum catalogues were checked to ensure the presence of the beads within the museums collections. The tombs that were selected then had to have datable material within the assemblage as well as faience beads in reasonable quantities. Access and destructive analysis of the beads found in these tombs was

then granted by all three museums. Therefore out of all of the assemblages in the Garstang Museum, Manchester Museum, and Bolton Museum from Garstang's excavations at Abydos every tomb that could be ascribed a time period that fell within this research remit, that had datable material, and faience beads were sampled. A total of 151 beads were sampled from 16 tombs. The assemblages from six Middle Kingdom tombs from the Garstang Museum were sampled, along with those of two tombs from the Bolton Museum (a total of 81 beads). Beads from another six tombs were sampled from the Garstang Museum to represent the New Kingdom with beads from one tomb from the Manchester Museum (total of 60 beads). The Second Intermediate Period was represented by beads from one tomb collected from the Garstang Museum (a total of ten beads).

Chapter 4: Methodology and Samples

4.1 Introduction

The methodology presented in this chapter is a general one, which revolves more around the samples than the analytical methods themselves. This chapter will present the sample methodology in three main steps. Step one is the process of sample selection, which describes why the specific beads were chosen to represent their particular assemblages. The second step includes the initial observations of the samples from their colour to their form to other general characteristics, and how these characteristics were determined. The third step will present the methodology for preparing the samples for analysis. There are several different types of analysis (SEM-EDS, EBSD, CL, and Sr isotope analysis) that were conducted on the faience samples, and all of them required the same preparation methods, except for the isotopic analysis, which will be discussed in Chapter 6. The methodology for each of the different analytical methods used in this research will be presented in the relevant chapters, along with details of how and why each method was chosen.

4.2 Sampling Strategy

The sampling strategy was the first step in undertaking this research, as each faience bead had to be carefully considered before it was selected for destructive analysis. Because the faience beads were selected on the basis of their provenance and availability (as discussed in Chapter 3), they were then further selected by the degree to which they appeared to represent their entire assemblages, in terms of colour and shape. The decision to randomly sample the assemblages was based on the suggestion made by Drennan (2004: 85) that "random sampling provides a basis for estimating how likely it is that our inferences about the population are wrong, and thus tells us how much confidence we should place in these inferences." This thesis is investigating the differences between the compositions of two time periods; therefore random sampling was selected to specifically identify differences in the population of faience beads from the periods of interest at the site of Abydos.

Only five or ten beads were selected from each assemblage for sampling, since it was considered important to attempt to keep the numbers simple/similar for statistical purposes, and to minimize the depletion of the actual bead assemblage, while nevertheless attempting to represent it thoroughly. The full bead assemblage information will be presented first by time period, then by museum, and tomb

number, in line with the way in which the tomb information was presented in Chapter 3. The colour and shape descriptions are presented in Tables 4.1 to Table 4.15. The Munsell colour and shape are presented in more detail for each bead in Appendix A.

4.3 Middle Kingdom Tombs

4.3.1 The Garstang Museum

4.3.1.1 TOMB 9 A'06 (E 9384)

Tomb 9 (Catalogue number E 9384) is a Middle Kingdom tomb that contained a total of 74 beads, of which 57 were made of faience, the rest being made from stone and shells (Figure 4.1). There were a variety of faience colours and shapes present in the assemblage (Table 4.1). The decision was made to sample three beads from the largest quantity of one type (27 oval, green, faience beads) to represent the majority of the beads in the assemblage. The same was done in the case of two samples from the sixteen brown faience disc beads, as they were the second most plentiful type of bead present. After that, singular beads were sampled from each remaining faience group, except for one (which was a possible pendant) because it was unique. The pendant was not selected since the colour and shape was already represented by another bead, and there was only one of this type. Also, the thesis is based on the analysis of beads, and as pendants are similar the typology can be more complicated.

Figure 4.1: Beads from Tomb 9 A'06 grouped by type and colour, bead 9384-1 presented for scale.

Bead Quantity	Material Type	Colour	Shape	Samples
27	Faience	Green	Oval	3
16	Faience	Brown/Black	Disc	2
2	Faience	Blue/Green	Disc	1
1	Faience	Blue	Cylinder	1
5	Faience	Blue	Cylinder	1
3	Faience	Black	Cylinder	1
2	Faience	Blue/Green	Pendants	None
1	Faience	Blue/Green	Poss. Pendant	1
5	Shell	White	Disc	None
1	Lapis	Blue	Oval	None
7	Carnelian	Orange/Red	Various	None
3	Stone	Blue	Ball	None
1	Stone	Blue/Green	Pendant	None

Table 4.1: Assemblage for Tomb 9 A'06.

4.3.1.2 TOMB 330 A'07 (E 2345)

This tomb's bead assemblage included 156 faience beads out of a total of 180 beads (Figure 4.2). Ten of these beads were sampled to represent part of the Middle Kingdom period (Table 4.2). Two different colours were represented in the assemblage: blue (6 samples removed) and red (four samples removed), and for each of these there were a variety of shapes. The most common shape was the disc type, which was sampled in both colours. The double disc shape was also sampled but, as there were far fewer of this type, only two were selected. Since there was only one decorated cylinder faience bead it was not sampled, and neither were the other non-faience beads.

Figure 4.2: Tomb 330 A'07 beads, strung to form a necklace. Bead 2345-5 for scale.

Bead Quantity	Material Type	Colour	Shape	Samples
114	Faience	Blue	Disc	5
1	Faience	Blue	Ball	1
6	Faience	Blue	Double Disc	None
1	Faience	Blue	Decorated Cylinder	None
31	Faience	Red	Disc	3
2	Faience	Red	Double Disc	1
1	Stone	Grey	Oval	None
2	Carnelian	Red	Disc	None
2	Metal	-	Spacers	None
14	Shell or Bone	White	Ball	None
2	Stone	Green	Ball	None
3	Glass	Blue	Disc	None
1	Stone	Brown	Ball	None

Table 4.2: Tomb 330 A'07 bead assemblage.

4.3.1.3 TOMB 359 A'07 (E 2379)

Middle Kingdom Tomb 359 A'07 contained 82 faience beads, of which ten were sampled (Figure 4.3). One of every type of bead within the assemblage was sampled, except one, an unusual large disc bead (Table 4.3). This bead was not sampled because it was the only one of its type present in the assemblage and an attempt was made to preserve the assemblage with at least one of each type.

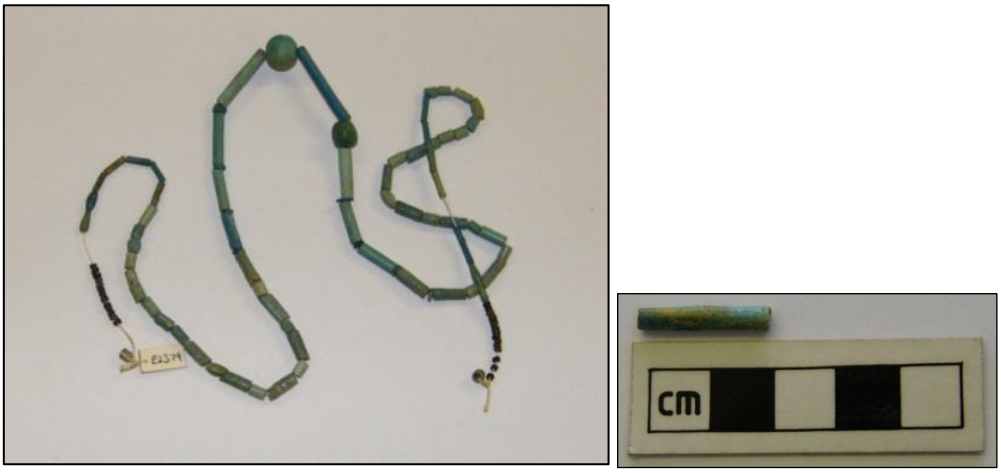


Figure 4.3: Faience beads from Tomb 359 A'07 strung together. Bead 2379-1 for scale.

Bead Quantity	Material Type	Colour	Shape	Samples
22	Faience	Green	Cylinder	2
1	Faience	Blue	Disc	None
2	Faience	Blue	Large Ball	1
27	Faience	Black/Brown	Disc	2
4	Faience	Blue/Green	Cylinder	1
11	Faience	Blue/green	Small Cylinder	1
6	Faience	Blue/Green	Disc	1
9	Faience	Green	Large Cylinder	2

Table 4.3: 359 A'07 faience bead assemblage.

4.3.1.4 TOMB 427 A'07 (E 2130)

The assemblage in Tomb 427 A'07 consisted of 342 faience beads, ten of which were sampled, representing all but two of the types present in the assemblage (Figure 4.4). One type was excluded based on the degraded state of the beads (the white/cream beads), and another (blue faience oval bead) was omitted since it was the only one of its kind (Table 4.4).

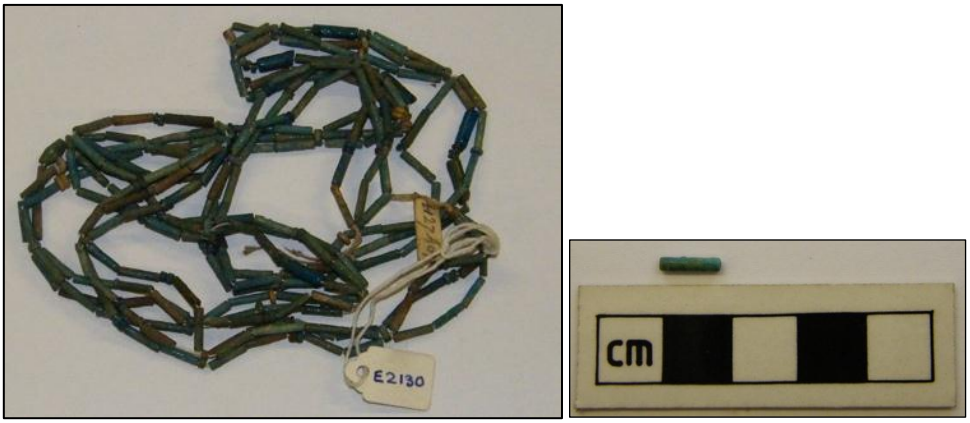


Figure 4.4: Assemblage from Tomb 427 A'07 strung together. Bead 2130-1 presented for scale.

Bead Quantity	Material Type	Colour	Shape	Samples
228	Faience	Blue/Green	Cylinder	5
83	Faience	Blue/Green	Disc	3
10	Faience	White/Cream	Disc	None
20	Faience	Blue	Spacers	2
1	Faience	Blue	Oval	None

Table 4.4: Faience beads from Tomb 427 A'07.

4.3.1.5 TOMB 475 A'08 (E 2435)

The assemblage from the Middle Kingdom Tomb 475 A'08 consisted of nineteen beads, of which eight were faience (Figure 4.5). Since this assemblage was so small, only five beads were sampled (Table 4.5). The three most common types were selected, including the one disc bead. It was decided to sample this one disc bead (going against the trend of preserving the singular faience bead types in an assemblage) because, generally speaking, disc beads are the most common type of faience bead found in this time period. A representative sample would aid in the overall goals of this study, so it was incorporated into the sample for this assemblage. However, the one example of an oval faience bead in the assemblage was not selected, because, conversely, it is not as commonly found at this date.

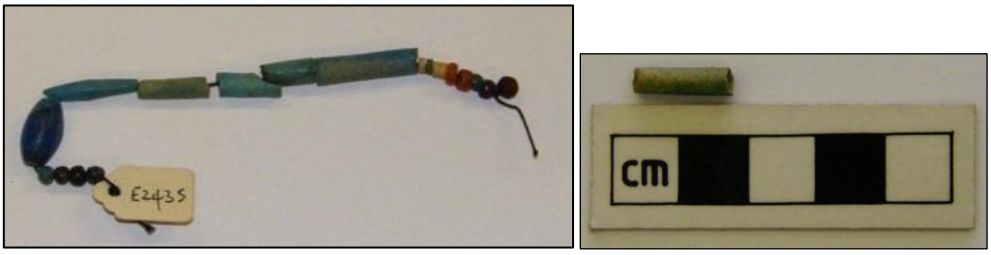


Figure 4.5: Beads from Tomb 475 A'08 with bead 2435-1 for scale.

Bead Quantity	Material Type	Colour	Shape	Samples
4	Faience	Blue	Cylinder	3
1	Faience	Blue	Disc	1
2	Faience	Blue	Ball	1
1	Faience	Blue	Oval	None
3	Shell	White	Disc	None
2	Stone	Brown	Ball	None
1	Lapis	Blue	Oval	None
2	Carnelian	Red	Ball	None
3	Garnet	Red	Ball	None

Table 4.5: The bead assemblage of Tomb 475 A'08.

4.3.1.6 TOMB 498 A'08 (E 2383)

This assemblage was originally sampled in the pilot project for this thesis (Hammerle 2008). The beads have been incorporated into this current research to add to the body of evidence and the dataset. There were a total of 59 beads in the

assemblage, however only a few were faience. Only six beads were sampled at the time to represent the bulk, without depleting the assemblage.

4.3.2 Bolton Museum

4.3.2.1 TOMB E 105 (54.00.75)

The assemblage from Tomb E 105 included 65 faience beads, of which ten were sampled (Figure 4.6). There were only two different colours represented in the assemblage and both were the same shape (Table 4.6), therefore the samples removed from each group should be representative of the whole assemblage.

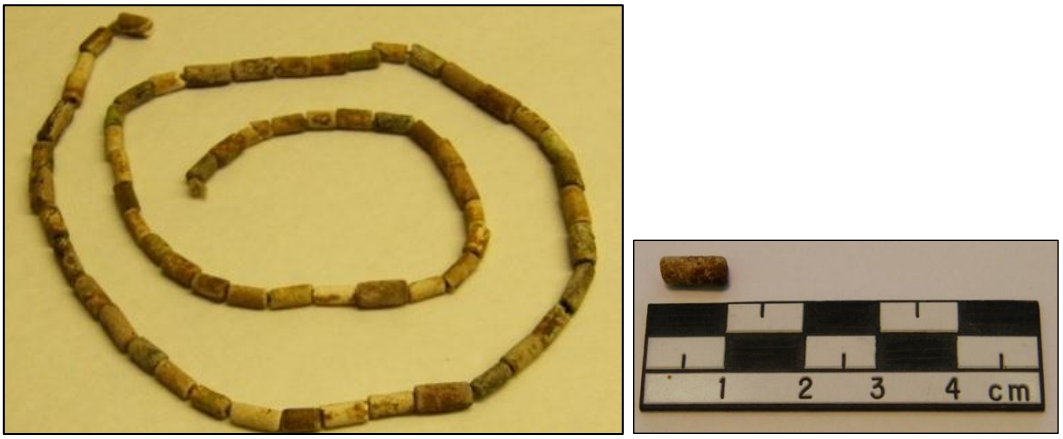


Figure 4.6: Faience beads from Tomb E 105 strung together. Bead 54.00.75-1 for scale.

Bead Quantity	Material Type	Colour	Shape	Samples
3	Faience	Pale Green	Cylinder	1
62	Faience	Brown	Cylinder	9

Table 4.6: The bead assemblage from Tomb E 105.

4.3.2.2 TOMB E 330 (54.00.79 and 54.00.79?)

There are two bead assemblages associated with Tomb E 330. The provenance of one of the assemblages has been questioned by Bolton Museum and has been marked with a question-mark to indicate its standing. Both assemblages have been sampled in order to determine their similarities and difference. The first assemblage comprises 84 faience beads, of which the ten largest were sampled (Figure 4.7; Table 4.7). One type, represented by five beads, was not sampled due to it being unrepresentative of the assemblage as a whole.

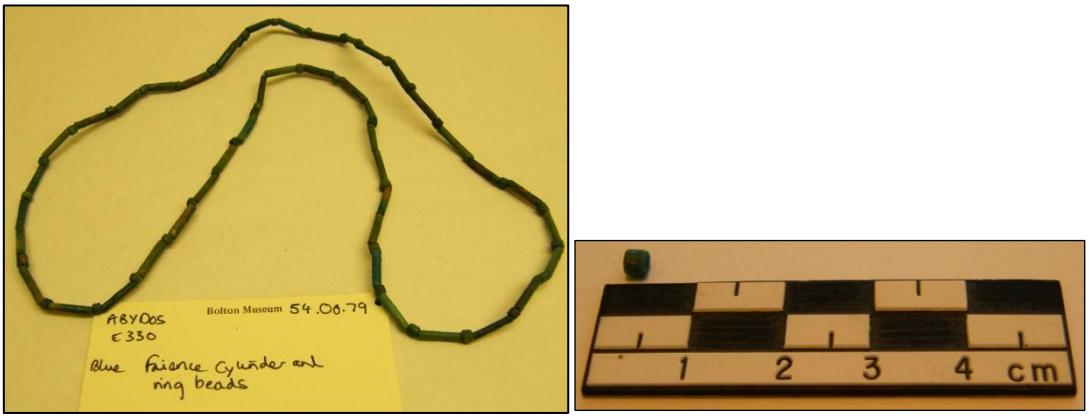


Figure 4.7: Assemblage one from Tomb E 330 strung together. Bead 54.00.79-1 for scale.

Bead Quantity	Material Type	Colour	Shape	Samples
43	Faience	Blue/Green	Cylinder	8
36	Faience	Blue/Green	Disc	2
5	Faience	Blue/Green	Square	None

Table 4.7: Tomb E 330 faience beads assemblage one.

Assemblage two from Tomb E 330 consisted of 53 faience beads (Figure 4.8). One individual red oval bead was not sampled, as it was the only one of its kind (Table 4.8). Ten were sampled which are of the cylinder type and similar to the eight sampled from assemblage one.

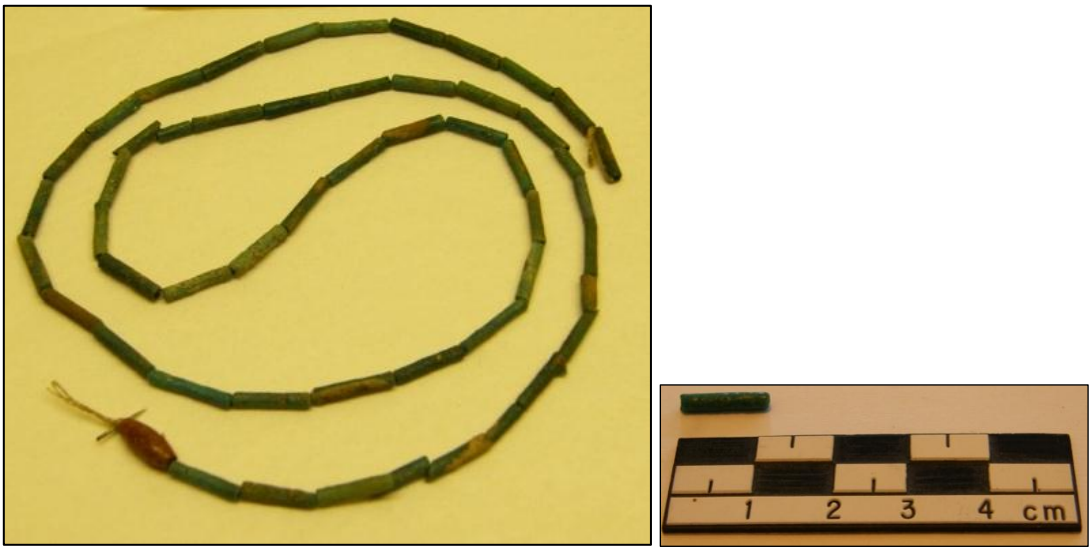


Figure 4.8: E 330 assemblage two faience beads strung together. Bead 54.00.79?-1 for scale.

Bead Quantity	Material Type	Colour	Shape	Samples
52	Faience	Blue/Green	Cylinder	10
1	Faience	Red	Oval	None

Table 4.8: Assemblage two faience beads from Tomb E 330.

4.4 Second Intermediate Period Tomb

4.4.1 The Garstang Museum

4.4.1.1 TOMB 458 A'08 (E 2385)

The assemblage for Tomb 458 A'08 consisted of 29 faience beads (Figure 4.9), ten of which were sampled. All of the types and colours of beads were sampled in numbers that aimed to represent the surviving proportions of these types (Table 4.9).

Figure 4.9: Faience beads from Tomb 458 A'08. The small blue faience bead (2385-3) at the end of the string is 2.86 mm in diameter.

Bead Quantity	Material Type	Colour	Shape	Samples
5	Faience	Blue/Green	Cylinder	2
1	Faience	Blue	Ball	1
23	Faience	Green/Yellow	Ball	7

Table 4.9: The faience bead assemblage from Tomb 458 A'08.

4.5 New Kingdom Tombs

4.5.1 The Garstang Museum

4.5.1.1 TOMB 492 A'08 (E 2380)

Tomb 492 A'08 included 60 faience beads out of a total of 88 (which consisted of gold and garnet beads), ten of these beads were sampled (Figure 4.10). The ten samples represented all of the different colours and shapes that were present in the assemblage (Table 4.10).

Figure 4.10: Tomb 492 A'08 bead assemblage strung together. Bead 2380-1 for scale.

Bead Quantity	Material Type	Colour	Shape	Samples
50	Faience	Blue	Disc	6
2	Faience	Blue	Large Disc	1
8	Faience	Black	Disc	3
2	Gold	Gold	Ball	None
24	Garnet	Red	Oval	None
2	Garnet	Red	Ball	None

Table 4.10: Assemblage for Tomb 492 A'08.

4.5.1.2 TOMB 525 A'08 (E 2384)

There were 75 faience beads in Tomb 525 A'08 assemblage (Figure 4.11). Ten of these beads were sampled (Table 4.11). Because there was a lot more variety in the colours of the faience beads in this assemblage, at least one of each type of shape and colour was sampled, so that each type is represented in the overall data set.

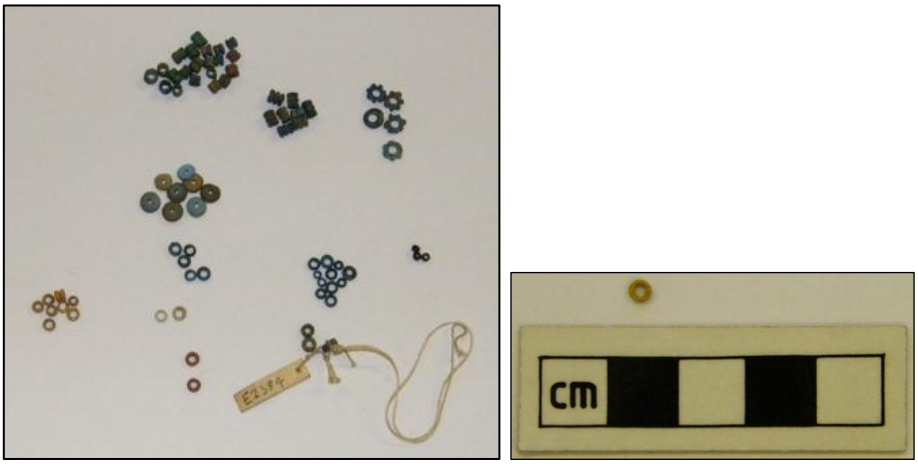


Figure 4.11: Faience beads from Tomb 525 A'08, bead 2384-5 for scale.

Bead Quantity	Material Type	Colour	Shape	Samples
8	Faience	Blue	Triple Barrel Cylinder	1
20	Faience	Green	Double Barrel Cylinder	1
8	Faience	Yellow/Green	Disc	1
5	Faience	Blue/Green	Sprocket	1
3	Faience	Black	Ball	1
2	Faience	White	Disc	1
2	Faience	Orange	Disc	1
8	Faience	Yellow	Disc	1
3	Faience	Green	Disc	1
16	Faience	Blue	Disc	1

Table 4.11: 525 A'08 faience bead assemblage.

4.5.1.3 TOMB 577 A'08 (E 2375)

The assemblage from Tomb 577 A'08 included a total of 119 beads, all of which were faience except for one which was a cowrie shell (Figure 4.12). Only one type of faience bead was sampled: the blue/green disc beads that were by far the vast majority of the beads in this assemblage (Table 4.12). Ten of these were sampled, both to represent the majority type and to preserve the one singular ball bead.

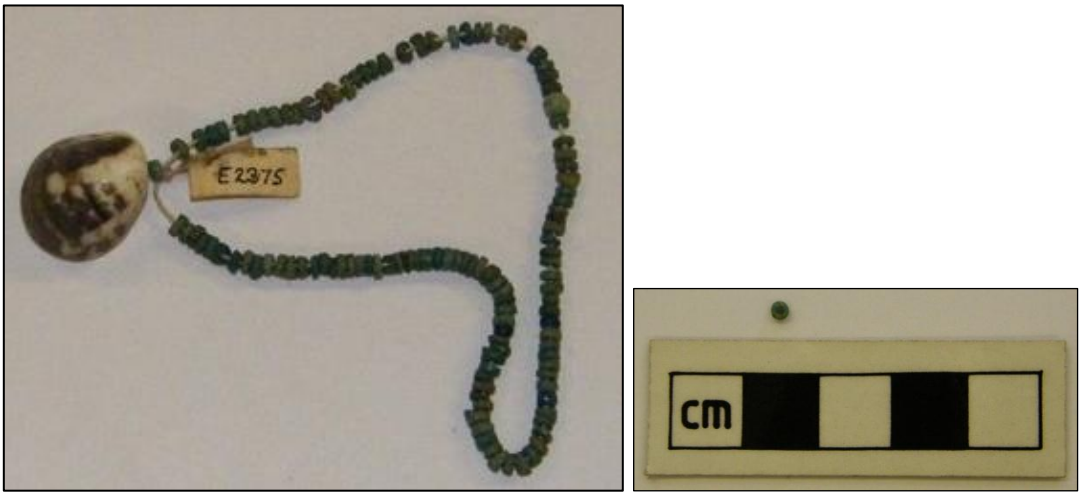


Figure 4.12: Assemblage from Tomb 577 A'08. Bead 2375-1 for scale.

Bead Quantity	Material Type	Colour	Shape	Samples
1	Shell	White	Oval	None
1	Faience	Blue	Ball	None
117	Faience	Blue/Green	Disc	10

Table 4.12: Faience and shell beads from Tomb 577 A'08.

4.5.1.4 TOMB 649 A'08 (E 2389)

Tomb 649 A'08 included a total of 263 beads, 243 of which were faience (Figure 4.13). Ten of these were sampled, mostly from the larger groups in the assemblage (Table 4.13). Bead types occurring only in ones or twos were not sampled, so that the bulk of the beads sampled represent the majority of the faience type in the assemblage.

Figure 4.13: Beads from Tomb 649 A'08 strung together. Bead 2389-1 for scale.

Bead Quantity	Material Type	Colour	Shape	Samples
161	Faience	Red	Ball	3
55	Faience	Blue	Disc	3
2	Faience	Blue	Triple Barrel Cylinder	None
12	Faience	Blue	Double Barrel	2
12	Faience	Red	Cylinder	2
1	Faience	Yellow	Disc	None
15	Shell	White	Disc	None
2	Stone	Green	Disc	None
1	Carnelian	Red	Jewel cut	None
2	Glass	Blue	Ball	None

Table 4.13: The bead assemblage of Tomb 649 A'08.

4.5.1.5 TOMB 942 A'09 (E 2344)

The assemblage from Tomb 942 A'09 contained 133 beads in total with only one being glass and the rest were faience (Figure 4.14). Once again the faience types with the smallest numbers (only one or two beads) were not sampled (Table 4.14). The other faience beads were sampled based on quantity to represent the bulk of the assemblage. Therefore, the types with over 50 beads were sampled with four beads removed and only two samples were removed from the type with only fifteen beads (ten beads in total were sampled).

Figure 4.14: Assemblage from Tomb 942 A'09 strung together. Bead 2344-1 for scale.

Bead Quantity	Material Type	Colour	Shape	Samples
55	Faience	Blue	Disc	4
59	Faience	Blue	Ball	4
15	Faience	Black/Brown	Disc	2
1	Faience	Red	Disc	None
2	Faience	White	Disc	None
1	Glass	Green	Ball	None

Table 4.14: Beads from Tomb 942 A'09.

4.5.1.6 TOMB 541 A'08 (E 2377)

As with the Middle Kingdom Tomb 498 A'08 (Section 4.2.1.6) this assemblage was part of the pilot project (Hammerle 2008). There were a total of fourteen beads in this assemblage, of which several were natural stone. Only five of the faience beads were sampled, having been selected on the basis of their shape and colour.

4.5.2 Manchester Museum

4.5.2.1 TOMB 18 A'06 (Man. 4075)

The Tomb 18 A'06 assemblage consisted of twenty-four faience beads and one metal bead (Figure 4.15). Five beads were sampled, all from the cylinder bead type (Table 4.15). This was done to preserve the assemblage as only a few millimetres at the end of each cylinder were taken for sampling.

Figure 4.15: Tomb 18 A'06 faience beads strung together. The fourth bead from the left is 4075-1, which has a length of 1 mm.

Bead Quantity	Material Type	Colour	Shape	Samples
12	Faience	Blue/Green	Cylinder	5
1	Faience	Blue	Mellon	None
3	Faience	Blue	Circular	None
2	Faience	Blue	Disc	None
1	Faience	Blue	Oval	None
1	Faience	Green	Oval	None

2	Faience	Blue	Large Oval	None
1	Faience	Blue	Pendent	None
1	Faience	Blue	Large Disc	None
1	Metal	-	Circular	None

Table 4.15: Tomb 18 A'06 bead assemblage.

4.6 Initial Inspection

Once the samples had been selected, they were subjected to an initial inspection before the beads were cut in half. This initial inspection was conducted in order to determine if there were any differences between beads from different periods, based purely on appearance. As Caple (2006: 21) points out "Objects are researched and often interpreted in terms of their physical appearance (form and decoration), which is used to give them a period, culture, association, and thus a date." This initial inspection consisted of photographing, drawing, weighing, Munsell colour analysis, microscopic inspection, and the conducting of Mohs hardness tests on all of the beads. The individual steps involved in this section will be discussed in depth below. The results of the initial observations of each bead is summarised in Table 4.16 and presented in full in Appendix A, categorised first by museum (Garstang, Manchester, Bolton), then by time period, catalogue number, bead number, and tomb number (e.g. Middle Kingdom, E2380-1, Tomb 492 A'08). Also included in Table 4.16 and Appendix A is the glazing method. This was determined by SEM analysis at a later stage. However, it is recorded here in order to present all of the bead information within one table (apart from the compositional details which can be found in Appendix G or H). From this point, the beads will be referred to by assemblage number alone (i.e. E2380-1). This is to simplify the identification of the individual beads, and the assemblage number was selected as the best option for doing this. The tomb numbers are not used because each tomb has many assemblage numbers associated with it (not only beads but for other artefacts as well) whereas the bead assemblage number refers specifically to the beads alone and can be referenced back to the tomb from whence they came.

4.6.1 Initial Recording and Classification

The bead samples were first photographed with a Fujifilm FinePix S 8000fd digital camera with super macro, which has a focus range of one cm to ten centimetres. This aided in recording the beads as the eye would see them. However, it should be noted that there was an inconsistent light source used during photography and the images are slightly affected by orange light rather than

daylight. This accounts for the slight variation in colour for the bead photos in Appendix A, and is why Munsell Charts were used to accurately record the actual colour of the beads using a consistent light source (Section 4.3.2). After the beads were photographed they were then drawn in order to record the shape and size in more detail, in case the photography misrepresented them due to shadowing. The beads are drawn to show the side profile, the above profile, and the perforation size. The darkened part of the bead profile is there to show the route/axis of the perforation through the bead. The beads were then measured using a carbon fibre digital calliper so that the proportions were accurately recorded to the nearest millimetre and are associated with the drawings of each bead (see Appendix A).

These drawings were then compared to those made by Snape (1986) in his thesis. All of the Garstang Museum and Manchester Museum beads were previously recorded by Snape (1986), and each bead was allocated a Roman numeral based on type (i.e. i), which is referenced for each bead where a match was made (see Appendix A). The beads were also subjected to Becks (1973) classification system (mentioned in Section 2.2.2, Appendix B), which is an attempt to create a standardised and universally accepted method of bead classification. This classification is presented under Snape's Roman numeral (i, Long cylinder I.D.2.b) in Appendix A. Once this was completed, the samples were then weighed using a Denver Instruments CE 08 TB Series scale to record every aspect of the beads before they were destroyed (i.e. cut in half).

4.6.2 Munsell

It is important to record the colour of an object, as this would have been important to the culture that created it (as stated in Chapter 2, and see also Caple 2006: 62). The Munsell Rock Colour Chart was used to record the colour of the faience beads, in order to link them to a universally accepted descriptive method. This system was originally developed to describe the colour of soil, rocks, and minerals using three terms which are given numerical designations; Chroma which is the maximum strength of the colour, Value which is based on the lightness or darkness of the colour, and last but not least the hue of the colour (there are ten major hues) (Jones and MacGregor 2002: 4). As an example, one of the beads might have the Munsell colour reading of 'Moderate Blue 5 B 5/6'. The '5 B' is representative of the hue of the colour, '5/6' represents the value and the chroma. The 'moderate blue' term at the beginning is a description of the Munsell colour and ensures that the colour attributed is accurate.

PERIOD	TOMB/Cat. #	BEAD TYPE	COLOUR	QUANTITY	PRODUCTION METHODS
MK	9 A'06/ 9384	Oval	Blue	1	Efflorescence, modelled, reed perforated
MK	9 A'06/ 9384	Oval	Green	1	Cementation, modelled, reed perforated
MK	9 A'06/ 9384	Oval	Brown/Black	1	Efflorescence, modelled, reed perforated
MK	9 A'06/ 9384	Disc	Brown/Black	2	Efflorescence, modelled, reed perforated
MK	9 A'06/ 9384	Disc	Blue/Green	1	Cementation, modelled, reed perforated
MK	9 A'06/ 9384	Cylinder	Blue	1	Efflorescence, modelled, reed perforated
MK	9 A'06/ 9384	Cylinder	Blue	1	Application, carved, drilled
MK	9 A'06/ 9384	Cylinder	Black	1	Cementation, modelled, reed perforated
MK	9 A'06/ 9384	Pendent	Blue/Green	1	Efflorescence, modelled, pierced
MK	330 A'07/2345	Disc	Blue	5	Efflorescence, modelled, reed perforated
MK	330 A'07/2345	Disc	Red	3	Efflorescence, modelled, reed perforated
MK	330 A'07/2345	Ball	Blue	1	Cementation, modelled, pierced
MK	330 A'07/2345	Double Disc	Red	1	Efflorescence, modelled, reed perforated
MK	359 A'07/2379	Cylinder	Green	3	Cementation, modelled, reed perforated
MK	359 A'07/2379	Ball	Blue	1	Cementation, modelled, pierced
MK	359 A'07/2379	Disc	Black/Brown	2	Efflorescence, modelled, reed perforated
MK	359 A'07/2379	Cylinder	Blue/Green	3	Efflorescence, modelled, reed perforated, one cementation
MK	359 A'07/2379	Disc	Blue/Green	1	Efflorescence, modelled, reed perforated
MK	427 A'07/ 2130	Cylinder	Blue/Green	5	Efflorescence, modelled, reed perforated
MK	427 A'07/ 2130	Disc	Blue/Green	3	Efflorescence, modelled, reed perforated
MK	427 A'07/ 2130	Spacers	Blue	2	Efflorescence, modelled, pierced
MK	475 A'08/ 2435	Cylinder	Green	1	Efflorescence, modelled, reed perforated
MK	475 A'08/ 2435	Cylinder	Blue	2	Cementation, modelled, reed perforated
MK	475 A'08/ 2435	Disc	Blue	1	Cementation, modelled, reed perforated
MK	475 A'08/ 2435	Ball	Blue	1	Cementation, modelled, pierced
MK	498 A'08/ 2383	Tooth	Blue	1	Cementation, modelled, pierced
MK	498 A'08/ 2383	Cylinder	Blue	1	Efflorescence, modelled, reed perforated
MK	498 A'08/ 2383	Disc	Blue	1	Cementation, modelled, reed perforated
MK	498 A'08/ 2383	Double Disc	Blue	2	Efflorescence, modelled, reed perforated
MK	498 A'08/ 2383	Ball	Greenish	1	Cementation, modelled, pierced
MK	E105/ 54.00.75	Cylinder	Orange/Brown	7	Wollastonite, cementation, modelled, reed perforated
MK	E105/ 54.00.75	Cylinder	Orange/Brown	2	Cementation, modelled, reed perforated
MK	E105/ 54.00.75	Cylinder	Green/Yellow	1	Efflorescence, modelled, reed perforated

PERIOD	TOMB/Cat. #	BEAD TYPE	COLOUR	QUANTITY	PRODUCTION METHODS
MK	E330/ 54.00.79	Cylinder	Blue/Green	18	Efflorescence, modelled, reed perforated
MK	E330/ 54.00.79	Disc	Blue/Green	2	Efflorescence, modelled, pierced
SIP	458 A'08/ 2385	Cylinder	Blue/Green	2	1 Cementation, 1 efflorescence, modelled, reed
SIP	458 A'08/ 2385	Ball	Blue	1	Efflorescence, modelled, pierced
SIP	458 A'08/ 2385	Ball	Green/Yellow	7	Wollastonite, cementation, modelled, pierced
NK	492 A'08/ 2380	Disc	Green	1	Cementation, modelled, reed perforated
NK	492 A'08/ 2380	Disc	Blue	7	Efflorescence, modelled, reed perforated
NK	492 A'08/ 2380	Disc	Black	2	Efflorescence, modelled, pierced
NK	525 A'08/ 2384	Cylinder	Blue/Green	2	Efflorescence, modelled, reed perforated
NK	525 A'08/ 2384	Disc	Green	1	Wollastonite, cementation, modelled, pierced
NK	525 A'08/ 2384	Sprocket	Blue/Green	1	Efflorescence, modelled, pierced
NK	525 A'08/ 2384	Ball	Black	1	Efflorescence, modelled, pierced
NK	525 A'08/ 2384	Disc	White	1	Efflorescence, modelled, reed perforated
NK	525 A'08/ 2384	Disc	Orange/Red	1	Cementation, modelled, reed perforated
NK	525 A'08/ 2384	Disc	Yellow	1	Efflorescence, modelled, reed perforated
NK	525 A'08/ 2384	Disc	Blue/Green	2	Efflorescence, modelled, reed perforated
NK	577 A'08/ 2375	Disc	Blue/Green	10	Efflorescence, modelled, reed perforated, one cementation.
NK	649 A'08/ 2389	Ball	Red	3	Efflorescence, modelled, pierced
NK	649 A'08/ 2389	Disc	Blue	3	Efflorescence, modelled, reed perforated
NK	649 A'08/ 2389	Double Barrel	Blue	2	Efflorescence, modelled, reed perforated
NK	649 A'08/ 2389	Cylinder	Red	2	Efflorescence, modelled, reed perforated
NK	942 A'09/ 2344	Disc	Blue	4	Wollastonite, cementation, modelled, pierced
NK	942 A'09/ 2344	Ball	Blue	4	Wollastonite, cementation, modelled, pierced
NK	942 A'09/ 2344	Disc	Black/Brown	2	Efflorescence, modelled, reed perforated, one cementation
NK	541 A'08/ 2377	Disc	White	1	Wollastonite, cementation, modelled, reed perforated
NK	541 A'08/ 2377	Cylinder	Green	1	Efflorescence, modelled, pierced
NK	541 A'08/ 2377	Oval	Green	1	Efflorescence, modelled, pierced
NK	541 A'08/ 2377	Oval	Yellow	1	Efflorescence, modelled, pierced
NK	541 A'08/ 2377	Ball	Green	1	Cementation, modelled, pierced
NK	18 A'08/ 4075	Cylinder	Blue/Green	5	Efflorescence, modelled, reed perforated

Table 4.16: Sampled bead types and their associated production methods as determined by initial inspection and SEM-EDS (MK is Middle Kingdom, SIP is the Second Intermediate Period, and NK is the New Kingdom).

The Munsell Chart was used to describe the colours of the faience bead samples analysed for this research, because this chart has blue and green spectra (the most common colours within the assemblages). Each bead's core and glaze was analysed using a daylight light bulb for a consistent tint free light source, and the Munsell colour was recorded (see Appendix A), in order to determine if there were any differences between the two, since faience has a structured body with several layers.

4.6.3 Microscope Observations

Initial observations of the beads were undertaken with the use of a low-power zoom microscope. This was done in order to distinguish any noteworthy features in the faience bead's form and/or exterior characteristics, including the basic composition of the object, if there are any tool, rest, or drip marks on the beads, or if there is any evidence for the use of moulds, or if there was any indication of use ware (Caple 2006: 31, Miller 2007: 23). The glaze quality and evenness of colour were recorded, as well as any signs of weathering. The production method was also determined, based on the presence of any sharp edges and intricate designs on the bead, indicating moulding, or any signs of the bead having been hand-made and modelled (discussed in Section 2.2.5). There was also the inspection of the perforation to determine whether the bead was pierced or formed over a reed. This would be based on any cracks forming at the mouth of the perforation, which would indicate the pressure of something being pushed in to form the hole (pierced). Reed perforation would be determined based on the type of the bead and if there was any 'tips' at the end of the beads where the perforation was created. That is if the bead was perforated in this way, the reed would have over extended from the bead and some paste would have remained on it. Once the reed is burnt away the remaining paste hardens to form little tips at the end of the bead. These observations were then recorded in Appendix A in the description column. Also, the inspection of the perforation attempted to determine if there was any use wear, such as the edges of the beads showing wear from the thread if they were worn daily. Unfortunately, no such determination was possible due to two factors: either the beads were so well glazed that no observable wear was identifiable, or the beads were so weathered that it was difficult to determine if the wear was due to use.

4.6.4 Mohs Hardness Test

The Mohs hardness test is named after the German mineralogist, Frederick Mohs, who developed the method of testing the hardness of a mineral based on a simple scratch test. The hardness is determined on the ability of the object to resist scratching. The item used for the scratching has a number on the Mohs scale of hardness (the softest is talc (=1), then selenite, calcite, fluorite, apatite, feldspar, quartz, topaz, corundum, and the hardest is diamond (=10)). This test was conducted on the glaze and the core of the beads (the latter done once the samples were cut, exposing the core). The results were then recorded as core/glaze (i.e. 3/4) (see Appendix A).

4.7 Sample Preparation

This section presents the general preparation that all of the faience bead samples went though for SEM-EDS, CL, and EBSD analysis. This includes the cutting of the beads, setting the halves in resin, grinding, polishing, and carbon-coating the samples. The remaining half of each bead, not set in resin, was then returned to the museums from which they were obtained, and then to their respective bead assemblages.

Each faience bead sample was cut in half (or in the case of long cylinder beads, a few millimetres at the end of the beads were cut off). The cutting was done with the use of a Mecatome P100 saw with a corundum blade. As stated in Section 4.3.4 above, corundum is rated 9 on the Mohs hardness scale, therefore the beads can be cut easily, leaving a suitable, flat face. The beads were then cleaned of the lubricant and dried, before one half of the bead was returned to the bead assemblage. The other half of the bead then became the research sample, and was set in a Teflon 30 mm diameter mould. Since the beads are relatively small, five samples were placed in each mould (therefore two moulds per assemblage, see Appendix C). Epoxy resin and hardener were then mixed and poured into each mould, and they were left to harden for 24 hours.

Once the resin was completely dry the resin block was removed from the mould. The sample blocks were then taken to the University of Liverpool's Engineering Department, to utilise their mechanical grinding wheels, which speed up the process, compared with grinding each sample by hand. The surface of each resin block was slowly ground down with the use of varying degrees of aluminium oxide grit paper and water as the lubricant, to ensure a perfectly flat surface for analysis. The grinding worked from the coarsest, 180 grit paper, to the finer, 2400

grit paper (the grit numbers refer to the number of grit particles per unit of area on the paper). The sample blocks were held in alternate directions to the wheel, so that the scratches would go in the direction in which the wheel was moving. This aided in determining if there were any scratches bigger than the grit currently being worked. Over time the scratches became smaller and smaller and a microscope would be used to gauge the quality of the grinding. This was done before each changing of the paper to the next finer degree of grit (180, 320, 600, 1200, and 2400), thus ensuring that there would be no scratches on the resin blocks that could compromise the geometry of the analysis on the samples.

Once the scratches were uniform and the sample had successfully been ground to 2400, the process of polishing began in the Department of Archaeology, Classics, and Egyptology's Archaeometallurgy Laboratory. The polishing wheel was used in order to remove any visible scratches and to create a perfectly clear surface for analysis. This was done in a similar way to the grinding, in degrees. However, instead of working up in numbers the polishing worked down from six microns to three microns then to one micron with the use of diamond paste that contained particles in these increments. At one micron the sample blocks looked as clear as glass with no scratches remaining. The sample blocks were then coated with carbon in an Emscope TS 500 sputter coater with carbon fibre string. The carbon is added to the surface of the blocks to ensure that there is no charging during SEM analysis; it achieves this by making the samples conductive. At this point the samples have been prepared and they are ready to be analysed the process of which is presented in the next chapter.

Chapter 5: SEM-EDS Analysis

5.1 Introduction

The previous chapters have provided the background on faience material from its origins to its usage. The discussion has also incorporated the artefacts that were made from faience material, including beads, such as those analysed to determine how faience technology changed over time. This was accomplished by considering their raw material sources and the way that they were produced. As Vandiver (1982: 167) has commented regarding her own work, this research is aimed at 'characterizing the diversity of manufacturing techniques and understanding the sequence of technological development'.

This chapter will present the main analytical method used to analyse these samples - scanning electron microscopy (SEM) coupled with energy dispersive spectroscopy (EDS). SEM-EDS was utilised to understand the production methods and chemical composition of the faience bead samples. SEM has been selected as a method of analysis because it can provide images of the microstructure and microtopography of the faience samples. These images can be used to determine the glazing method utilised, and SEM can then be coupled with EDS, which provides the chemical analysis of the faience samples. The data gained from EDS determines the nature of the raw materials utilised in the production of the faience material, including the alkali, silica, and colourant sources (Tite *et al.* 2007: 1569). This chapter presents the background to SEM-EDS, from how the methods work, to how the analysis was conducted on these samples. The results and discussion will then be presented, followed by a conclusion, which compares the results of the time periods of interest against each other, to determine how the technology changed.

5.2 Background

Several different approaches have previously been employed in order to understand vitreous materials by archaeologists, conservation scientists, and art historians (Harris 1977: 343, Mass 1999:15, Thomas 1956: 77). However, in the last few decades, techniques used in the physical sciences have been adopted to study archaeological material with great success (Jones 2004: 331, Perrot 1999: 1). This includes the study of vitreous materials such as glass, glazed ceramics, and faience, where the chemical composition is a key factor in understanding production techniques, regional variations, and the chronological changes that have occurred over time with the world's oldest synthetic material.

Extensive analysis has been conducted on ancient glass, which has the same chemical composition as faience, namely soda, lime and silica. The main difference between the two materials is the quantity of alkali, and the control of the furnace/kiln used for the manufacture of glass (Romich 1999: 6). Arriving in Egypt after faience had been used for several thousands of years, glass production influenced faience production with new colourants that were previously unused (Groot *et al.* 2006: 229). In recent years, ancient glass has been subjected to several different types of analytical study, and the research on this vitreous material far exceeds that conducted on faience material. Consequently, some of the research conducted on glass is incorporated into this thesis to fill in gaps and contextualise some of the results obtained on faience material. After all, as stated in Section 2.1.6, faience and glass could have been made in the same workshops, and perhaps with the same raw materials.

Several different methods have been used to study glass materials, including electron microprobe (both energy and wavelength dispersive detection), proton-induced x-ray emission spectroscopy (PIXE), atomic absorption spectroscopy (AAS), and many others (Bronk and Freestone 2001: 517, McGovern 1987: 91, Tite *et al.* 2007: 1568). SEM, however, is one of the main methods used to analyse glass and glazes because it provides quick, cheap, and reliable data, and can be run in conjunction with spectroscopic methods such as EDS (Barber et al. 2009: 115, Bronk and Freestone 2001: 517), as accomplished in this research.

One of the major differences between the study of glass and faience is the fact that faience research requires access to all layers of the material (core, glaze, and interparticle glass), which do not occur in glass. The analysis therefore needs to be conducted on broken fragments of material, or else an item needs to be subjected to destructive methods to retrieve a suitable sample. Glass, on the other hand, is a homogeneous material, and can be analysed at any given area, which should be representative of the bulk.

Several different analytical methods have been utilised in the study of faience which mirror the methodology used for glass analysis, such as atomic absorption spectroscopy (AAS), as discussed in Chapter 2 above (Section 2.1.4) (Guralnick 1988: 138). X-ray fluorescence analysis (XRF) was another popular method for analysing faience in the 1980s, such as the work conducted by Foster (1987: 57) on Minoan faience from the Ashmolean Museum. However, most of this work has either been surface analysis of the glazed area only, or semi-quantitative in nature (Kaczmarczyk and Hedges 1983, Tite *et al.* 2007: 1568). There has also been the exploration of new methods on material similar to faience, such as work

undertaken by Freestone *et al.* (2009 b: 8) using thin-section polarized light microscopy and inductively coupled plasma atomic emission spectrometry (ICP-AES).

SEM-EDS analysis was chosen for this research for several reasons, the main one being the fact that the faience beads could be subjected to imaging and chemical analysis at the same time. The SEM-EDS analytical method is rapid, quantitative and multi-elemental, and the full bead can be viewed and analysed while being preserved in a resin block, which preserves it for re-analysis (Leute 1987: 106, Mass 1999: 19). The data provided by SEM-EDS should be relatively reproducible and accurate within a small margin of error, which will be discussed further in Section 5.3.1. It also provides the opportunity to analyse all three layers of the faience beads separately, without having to do bulk analysis.

5.2.1 Scanning Electron Microscopy

The scanning electron microscope has an electron beam that scans across the sample at variable energy levels from 1 kiloelectron volt (KeV) to 30 KeV (Leute 1987, Parkes 1986: 185, Goodhew *et al.* 2001: 122). Since the wavelength of an electron beam is smaller than that of light, which is used by conventional microscopes, it gives better depth of field and resolution, which can almost give the sample a three-dimensional appearance (Goodhew *et al.* 2001: 2-3, Williams 1994: 159). This means that the 'hills' and the 'valleys' of a sample can be in focus at the same time, which is important when working with a porous material such as faience (Freestone 1985: 67-68). The magnification of the SEM can go up to x200,000 but it is normally used within the range of x10 to x5,000 (Caple 2006: 195).

The electron beam is controlled and produced by an electron gun assembly, which requires careful alignment of several components including the electron gun, the condenser lenses, the scan coils and the detectors (Figure 5.1) (Goodhew *et al.* 2001: 3). The electron beam passes through the anode hole, and then through a series of magnetic 'lenses' (actually coils). These lenses de-magnify the beam to a specific diameter (spot size), which illuminates a corresponding area of the sample being analysed (Tite 1972: 246). The condenser lenses usually control the beam diameter, and this is particularly important because it affects the resolution of the microscope as it deflects the beam over the surface of the sample, during the scan (Chescoe and Goodhew 1990: 16, Tite 1981: 200). The samples have to be conductive, and are often covered in a thin layer of carbon to limit charging, which can happen when the sample is bombarded with electrons and can cause interference. Also the whole system needs to be under vacuum, which is necessary

for the electrons not to be scattered by the gas molecules in the air (Goodhew *et al.* 2001: 20, Leute 1987: 123).

The interaction of the beam with the samples results in the emission of several different signals, such as secondary electrons, backscatter electrons, and x-rays (Goodhew *et al.* 2001: 125). The SEM is primarily an imaging method, the images are greyscale, and have good depth of field (Ponting 2004: 166). There are two primary imaging modes: secondary electron image (SEI) and backscattered election image (BEI) (Potts 1995: 380, Tite 1972: 246). The distinction between the two types of electrons is the angle of incidence of the primary electron beam. Both types of electron are counted through a scintillator, which sends the electrical signal produced to the display as an image (Chescoe and Goodhew 1990: 1-2, Goodhew *et al.* 2001: 130).

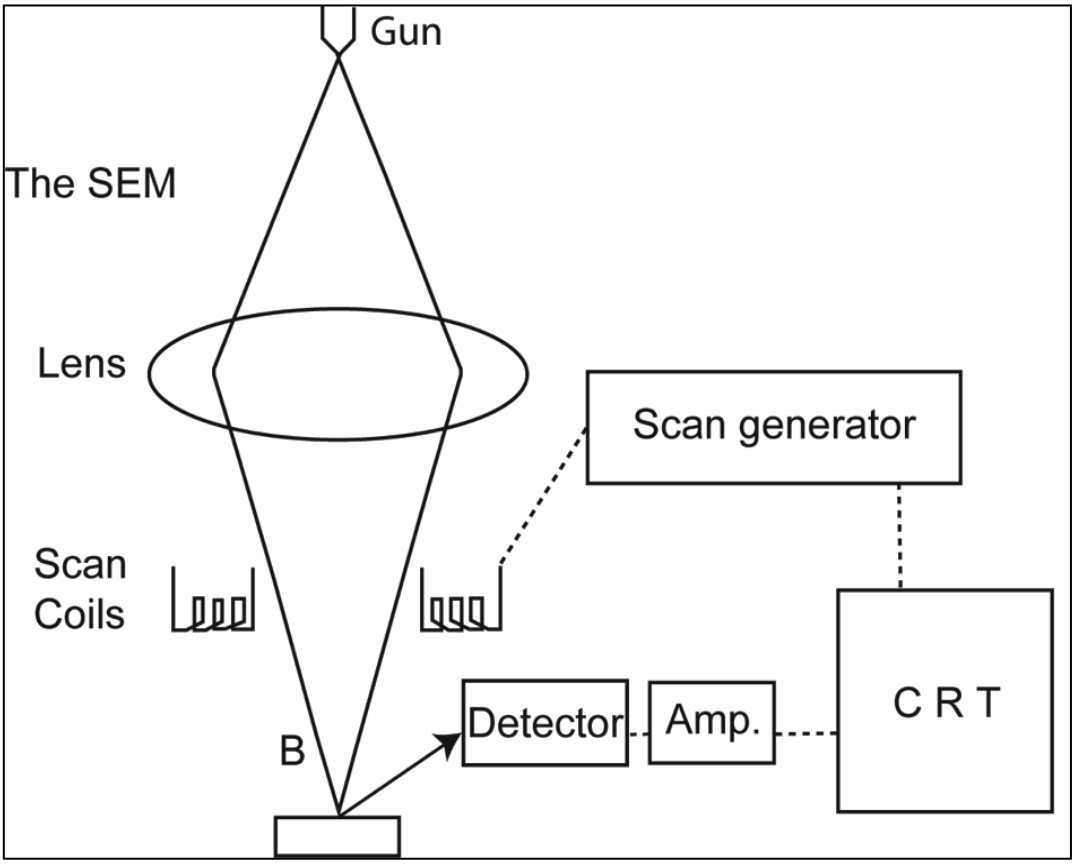


Figure 5.1: The SEM (adapted from Chescoe and Goodhew 1990).

5.2.1.1 SECONDARY ELECTRON IMAGING

Secondary electron imaging (SEI) consists of the secondary electrons ejected from the atoms of the sample as a result of primary electrons colliding with these atoms (Caple 2006: 197, Parkes 1986: 186, Tite 1972: 247). It is these

electrons that form the secondary electron reading and image. Those electrons with lower energy than the primary electrons escape the surface of the sample, and it is the overall number of these secondary electrons that are counted to form the image, providing a detailed picture of the microstructure of the surface (Parkes 1986: 186). The number depends also on the surface topography and the angle of the primary beam to the surface of the sample (Leute 1987: 123). This method of imaging occurs when the secondary electrons collide with a phosphor or scintillator, which then emits light. The light is converted into photons by a scintillator-photomultiplier system, also known as the Everhart-Thornely detector (Chescoe and Goodhew 1990: 20, Goodhew *et al.* 2001: 129). The photomultiplier then converts the photons into electron pulses, which are then amplified by the cathode ray tube (CRT; see Figure 5.1).

This system is usually built into the SEM and is the most commonly used imaging mode, because it has excellent depth of field for microstructure analysis (Goodhew *et al.* 2001: 129). SEI is utilised to study the surface texture (microtopography) of the sample, and, as stated earlier, this is dependent on the angle between the specimen surface and the beam. The images that are generated are in greyscale, with varying shades of grey, without any sharp boundaries, and are reflections of the angle of the surface to the detector (Freestone 1985: 67-68). Alternatively, backscatter electron images provide variations in the greyscale based, on the atomic number of the elements present (Henderson 2000: 18).

5.2.1.2 BACKSCATTER ELECTRON IMAGING

When the electron beam hits the surface of the sample, the primary electrons are deflected by the charge on the atoms, and bounce back. These are the so-called 'backscattered electrons' (Caple 2006: 197, Goodhew *et al.* 2001: 75, Parkes 1986: 185). The backscatter electrons are reflective of the atomic number of the atoms that they interact with; heavy elements deflect better than lighter elements. The number of electrons increases with the atomic number of the element present.

The backscatter electron information is compiled by a scintillator detector (e.g. Robinson *et al.* 2004), attached to the SEM, to form an image based on the number of the backscattered electrons and the ways in which they vary over the surface analysed (Ponting 2004: 168). The higher the atomic number of the sample area, the lighter/brighter it appears in the image (with variation in greyscale; see Goodhew *et al.* 2001: 75-76). Copper is almost white in greyscale, whereas silica is grey, and the voids appear black. The detector is normally located to one side of the

sample because the backscattered electrons travel in straight lines (Henderson 2000: 18). The detector is often retractable because it can restrict the working distance of the SEM and interferes with the detection of the x-rays (Goodhew *et al*. 2001: 130).

This method of imaging is very useful when it comes to faience analysis, and is complimentary to SEI and EDS. BEI encompasses both of the other signal types received from the SEM (SEI and EDS). It provides an image of the microstructure of the sample, and it also provides an indication of the chemical composition of the surface of the material (Henderson 2000: 19, Freestone 1985: 68, Ponting 2004: 168, Tite 1972: 248). The latter is very useful for studying faience, as it depicts the differences between the glaze, interparticle and core layers of faience, based on the atomic numbers of the elements present. Since copper has a higher atomic number than silica, the copper-rich glaze appears brighter than the silica. However, this is only an image, which is useful for determining glazing method and viewing the microstructure of the sample. EDS analysis still needs to be conducted in order to determine the specific elements that are present, and in what quantities.

5.2.2 Energy Dispersive Spectrometry

As in the case of secondary and backscatter electrons, secondary x-rays are emitted from the faience sample as a result of it being bombarded by the electron beam of the SEM (Caple 2006: 198). These x-rays are counted by an automated scintillator, which consists of a semi-conducting silicon or germanium crystal mounted at the end of a copper cold finger (liquid nitrogen chilled) and read through a beryllium window (Figure 5.2) (Goodhew *et al.* 2001: 175, Potts 1995: 286, Potts *et al.* 1985). The temperatures maintained by the liquid nitrogen minimize electronic noise, which can affect the determination of smaller signals (Potts 1995: 290).

This is energy dispersive spectrometry (EDS), a method, which measures the energy levels of the pulses (x-rays collected simultaneously) to determine the elements present (Henderson 2000: 8, Leute 1987: 124). The number of the pulses is diagnostic of the intensity of that particular element, which is represented as peaks on a histogram (Ponting 2004: 169, Potts 1995: 286). Each peak represents a different element (energy), and the height of this peak is indicative of the concentration of the element. This works very well for multi-elemental samples each element is represented in the histogram and is proportional to the amount of the element in the material (Freestone 1985: 68).

The main advantage of EDS is that it can be run concurrently with SEM. This method can be used for bulk analysis (large and small areas), spot analysis (very

small point) and line analysis. The small sample size and the ability to select areas of the sample for analysis make it possible to avoid weathered areas or voids (Verita *et al.* 1994: 241). EDS not only has very good resolution when run above 10 KeV (Potts 1995: 286) but is also applicable to many different materials, and is overall a very versatile system (Goodhew *et al.* 2001: 175). It is quantitative, rapid, and conducted at the same time as imaging (SEI and sometimes BEI). EDS is comparable to wavelength dispersive spectroscopy (WDS) when it comes to silicate minerals, and is more readily available than WDS, which is why it was selected for this research (Verita *et al.* 1994: 242-250).

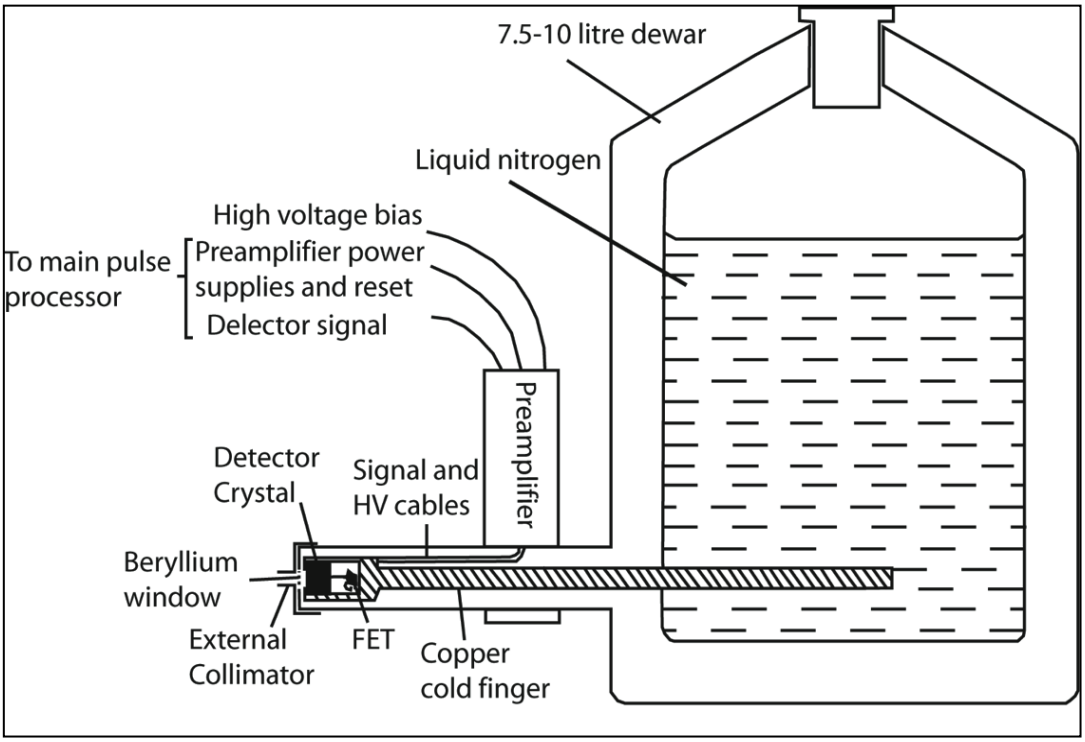


Figure 5.2: Energy dispersive detector (adapted from Potts 1995).

5.3 Methodology

This methodology continues on from Chapter 4, which presented the sample preparation process. All the SEM analysis was conducted on the Jeol JSM-5300 in the Department of Archaeology, Classics, and Egyptology, University of Liverpool. This SEM was coupled with a Princeton Gamma-Tech Avalon Spirit EDS system. The general running of the SEM and EDS system will be discussed in this section, along with the specifics of calibrating the system, standards, acquiring data, experiments, and the processing of these data.

5.3.1 Calibrating the SEM-EDS

Before conducting analysis on the faience beads, the system needs to be calibrated. The SEM-EDS system is turned on and then left to run for an hour prior to conducting any analysis, to ensure that the electronics are stable. The first step in the process of calibrating the SEM-EDS for quantitative analysis is to set up the standards from which the EDS system calibrates. A copper standard is analysed to check the stability of the beam and to see if there is any energy drift. Copper is ideal for this as it has only two peaks (La and Ka), and can be read at all energy levels (i.e. 10, 20, 40, and 80). This calibration is conducted for 100 counts, at a magnification of 2,000, 20 KeV, 20 mm working distance, and at a 30^{o} tilt, as is all other analyses (unless stated otherwise). Once the electronics are stable, calibration by mineral standards can be undertaken.

A block of thirteen multi-elemental mineral and pure metal standards were analysed and saved in the EDS standards library to create the standards for specific elements related to glass and faience. As stated by Goodhew *et al.* (2001: 379) “the success of any quantification depends on there being suitable standards whose characteristic x-ray counts maybe compared with those from the specimen”. The mineral standards are perfect for this analysis as they vary from pure elements, such as copper, to multi-elemental minerals such as Wollastonite. The samples were analysed first with small area analysis, then spot analysis, to see if there was any variation between the methods. It was determined that if there was any variation in the analysis techniques, it was minimal and undetectable. Thus the analysis was conducted at 2,000 times magnification on each mineral standard and on the Corning standard reference glass. These standards were then checked against the Corning glass standards to determine their precision and accuracy and hence their acceptability for analysing glass and faience.

The Corning Glass Standards are soda-lime-silica glasses (except C which is a lead glass), which were produced by Corning Incorporate New York, NY in 1964 and are similar to ancient glass from the Mediterranean and Near East (Brill 1999: 7, Bronk and Freestone 2001: 518). These standards are internationally known and have certified values (Table 5.1). Corning A was analysed as a secondary standard to check that the mineral standards were quantitatively accurate when applied per element to A, and that the totals were within 97% to 103% of the certified values. This enabled the author to select those specific elements that would be used in the analysis of the faience samples, and the results can be seen in Table 5.2.

OXIDES	Comp. % CORNING A	Comp. % CORNING B	Comp. % CORNING C	Comp. % CORNING D
SiO_2	66.56	61.55	34.87	55.24
Na_2O	14.52	17.26	1.20	1.32
K_2O	2.93	1.10	2.73	11.46
CaO	5.30	8.71	5.06	15.05
MgO	2.81	1.19	2.84	4.09
Al_2O_3	1.01	4.22	0.88	5.43
Fe_2O_3	1.09	0.35	0.33	0.50
MnO_2	1.18	0.28	0	0.57
Sb_2O_5	1.72	0.46	0	0.96
PbO	0.08	0.40	36.91	0.27
CuO	1.22	2.70	1.17	0.40
CoO	0.15	0.035	0.17	0.022
BaO	0.54	0.14	12.09	0.33
TiO_2	0.80	0.10	0.82	0.40
SnO_2	0.28	0.04	0.22	0.13
SrO	0.10	0.01	0.10	0.05
Li_2O	0.01	0.001	0.01	0.005
Rb_2O	0.01	0.001	0.01	0.005
V_2O_5	0.006	0.03	0.006	0.015
Cr_2O_3	0.001	0.005	0.001	0.0025
NiO	0.03	0.09	0.03	0.06
ZnO	0.04	0.20	0.04	0.10
ZrO_2	0.005	0.025	0.005	0.025
Ag_2O	0.002	0.01	0.002	0.005
Bi_2O_3	0.001	0.005	0.001	0.0025
P_2O_5	0.14	0.84	0.09	4.02
Cl	0.10	0.20	0.10	0.40
$S0_3$	0.16	0.54	0.16	0.30
Total	100.795	100.492	99.845	101.1495

Table 5.1: Corning glass standards (Corning A-D) by oxide and compound percent.

Element	Mineral Standard
Sodium	Jadeite
Magnesium	Periclase
Aluminium	Jadeite
Silica	Jadeite
Potassium	Orthoclase
Calcium	Wollastonite
Iron	Pyrite
Copper	Pure Copper
Manganese	Pure Manganese

Table 5.2: Mineral standards selected per element for faience analysis.

The Corning glass standard A was also used to calculate the precision and error of the analyses (Table 5.3), and measurements were taken at the beginning and end of each session (Appendix D). The iron and copper error is high, which is due to the Corning Glass Standard A having low quantities of both elements which are close to the limit of detection levels (mentioned below). It is very important to determine the accuracy and precision of the EDS system because the results can vary for each element, and this is why multi-elemental standards were used (Caple 2006: 25). This process was carried out in order to record the stability of the EDS system and to check the sodium levels.

Oxides	% Error	Precision %
SiO_2	± 1.19	±3.01
Al_2O_3	± 48.12	±14.56
CaO	±35.00	±4.43
MgO	±8.97	±8.10
Na_2O	±9.00	±5.56
K_2O	±19.16	±4.69
Fe_2O_3	±104.01	±8.60
TiO_2	±54.38	±7.09
CuO	±105.01	±7.57
MnO_2	±49.50	±33.08

Table 5.3: Error and precision for the SEM-EDS as determined by Corning A.

Corning A was also used to determine if sodium burn-off was an issue with this specific SEM-EDS system. If there is sodium burn-off it would affect the quantitative analysis of sodium, and the levels recorded for the element would be incorrect, and therefore any interpretations based on these results could be wrong (Goodhew *et al.* 2001: 20). The first experiment was based on the work of Henderson (1988: 78-79), in which he defocused the beam to limit sodium burn-off. In order to replicate Henderson's work, the analysis procedures were changed, such as the amount of seconds altering 100 to 200, and the counts decreasing from 2,000 to 1,000. This increases the count time, but decreases the amount of energy interacting with the surface of the sample, to limit burn-off of the sodium. The results of this experiment were actually lower than the average sodium levels before changing the energy levels. The sodium reading is normally between 12% and 14%, which is very close to the Corning A certified value of 14.52%. During this test, the sodium value was 9.45-10.45%. This EDS system has a thin window detector and can obtain better results at lower energy levels, which means there is less sodium burn-off from the sample. Therefore, Henderson's method of sodium preservation was deemed to be inappropriate for this research.

Another experiment was conducted by analysing the Corning A standard at the beginning of each session (starting March 22, 2011), six times in succession with spot analysis, to see if the readings varied per spot, and if so by how much. The assumption was that if there was sodium burn-off, the amount of sodium of each spot analysis would be lower than the last. This test was conducted at 200 times magnification, at a working distance of 20 mm, and at 20 KeV. The results indicate that the sodium levels are quite stable for spot analyses one to six, but slightly lower than the Corning A standard of 14.52%, with averages around 10-13% (Appendix E). Therefore, a global correction for the faience beads could be taken into consideration to account for any sodium burn-off, since the faience beads are all analysed using spot analysis.

5.3.2 Data Acquisition

After the calibration of the SEM-EDS system, and the determination of the accuracy for each element, the main analysis was carried out. In order to explain how the data were acquired, descriptions of the way in which each session was conducted will be presented here. This will include some of the information provided above, to present the procedure both in full detail and step by step.

Every session of analysis started after the SEM-EDS system was left on for an hour to warm up and stabilise. Then the Corning A analysis was undertaken at

20 KeV, 2,000 magnification, 30^{o} tilt, and with the sodium results at 12%-14% and the totals at 97%-103%. After the bulk analysis of Corning A was completed, the six points were taken with the SEM at 200 times magnification. Once this was done, the Corning A block was removed from the SEM, and the faience bead sample block was installed.

There are five faience beads per block, in order to limit the exchange time. The beads were all inspected using SEI imaging then analysed with BSI imaging (Appendix F). First the whole bead was imaged (at a magnification of x35) and then two areas were selected for profiling (at a magnification of 50-200 depending on the bead size). Within these two areas selected for profiles, six spot analyses were then conducted: two spots on the surface area, two in the interparticle zone, and two in the core area. This method of analysis was chosen in order to get in between the silica particles to test the multi-element interparticle glass, which would have the elements necessary to determine production methods.

While the spectrum was acquiring data, the mineral standards were set for each element (as shown in Table 5.2). The resulting spectrum and report were then saved, and the results entered into an Excel workbook (Appendix G). This was then repeated for each bead until the end of the session. Before the SEM-EDS was shut off, the faience sample block was removed and the Corning standards block put in. At the end of the session a further measurement on the Corning A block was then taken and the instrument shut down.

5.3.3 Processing Data

The collection of the data is arguably the easiest part of the compositional analysis process. After all of the information was collected for each point and entered into Excel, it then needed to be subjected to statistical analysis (the raw data for which is presented in Appendix G). The first step in processing the data collected is determining the 'limits of detection' (LOD). This is very important to establish for any analytical method, as it states the minimum limit that the instrument can analyse of any specific element (Potts 1995: 16). This is especially significant for elements expected to be present in low concentrations, since the peak of the element needs to be distinguished from the background counts, which will affect the accuracy and precision of the SEM-EDS (Goodhew *et al.* 2001: 199).

Newbury and Myklebust (2003: 28) produced a paper on determining the limits of detection for energy dispersive x-ray spectra based on an equation that requires a multi-elemental standard. This need is fulfilled by the use of the Corning A standard, which has all the main elements necessary for analysing faience. The

minimum detection levels were calculated based on the results of the Corning A standard. The best results for the limits of detection were twice the standard deviation of the mean, in other words the equation, which works out as:

$$2 \times \sqrt{BG} \times Cert. \div \text{Net Counts}$$

(BG=background counts, Cert.= certified value of the element).

The results of this equation are presented in Table 5.4.

The minimum limits of detection (LOD on cert%) results were inserted into the blanks of the Excel workbook to prevent the blanks being counted as zero, in case an element was present in too low a quantity for the instrument to detect. This was done for the main elements (based on the analysis of the Corning A results). Other elements that appeared rarely, or were not significant for interpreting the methods of faience production, were left as non-detected.

Element	Cert %	Wt%	LOD on Wt %	LOD on cert %	MDL
Na	10.77	9.9	1.14	0.83	0.25
Al	0.54	0.76	0.62	0.29	0.10
Si	66.56	31.17	0.53	0.76	0.07
K	2.43	2.88	0.75	0.42	0.09
Ca	3.79	5.27	0.84	0.40	0.10
Fe	0.762	1.63	2.07	0.65	0.25
Cu	0.98	2.15	2.80	0.85	0.35
Mn	0.91	1.38	1.57	0.69	0.19
Ti	0.48	0.71	1.04	0.47	0.13
Mg	1.69	1.49	0.83	0.63	0.15

Table 5.4: Limit of detection for the main elements analysed.

Once the limits of detection were entered into the workbook, the main body of data had to be dealt with statistically. There were 935 individual spot analyses collected, which were then averaged out, based on layers within the bead (glaze, interparticle glass, and core). An average for the whole bead was then calculated. As Orton (1980: 19) states: “the role of mathematics, and especially of statistics, is to provide a framework within which this mass of evidence can be sifted, and useful information detected”. One of the common practices for processing compositional data is to normalise or standardise it in some way (Baxter 1995: 513). However, due to the thoroughness of the data collection process for this research (maintaining totals within 97% and 103%) the totals were not normalised, to 100%. Therefore, the amounts of each element are accurate representations of the analysis and not statistically altered to equate 100%. Conducting statistical analysis on these beads

is essential to determine if there are any groupings based on time period, and ultimately to determine if there was any variation in the technology of faience. The statistical analysis was conducted with the use of SPSS software. The Excel data were imported into SPSS and then the variables were selected for comparison. All of the data underwent logarithmic transformation, tendency in order to 'stabilise the variances of the variables', and since the data were not normalised, this helped to sort out any possible issues or problems with the data (Baxter 1995: 515). The graphs generated from the SPSS analysis are presented in the next section, with a discussion of what they may mean regarding the interpretation of faience production.

5.4 Results and Discussion

The results of all of the SEM-EDS analysis will be presented in this section, along with discussion of a few of the experiments that were undertaken. These experiments were conducted in order to test the usefulness of elemental mapping and line analysis for faience materials. As this PhD research sets out to develop a methodology for studying faience beads, the decision was made to utilise all that the SEM-EDS system has available, and determine if the features are useful for interpreting faience. The results of the SEM-EDS analysis will then be presented, along with the discussion on the determination of the production methods, raw materials utilised, and the comparison of technology from each of the time periods of interest. These results will also be discussed in the context of preconceived notions of the characteristics identified with faience from these time periods.

5.4.1 SEM-EDS Experiments

Two different experiments were conducted using elemental mapping and line analysis on several of the faience beads, to determine the future usefulness of such methods for understanding the material. Ten beads were selected from the Garstang Museum collection. The other museum assemblages were not sampled because they contain fewer beads and the beads were chosen to be as representative of the whole sample assemblage as possible. The ten beads that were selected for analysis were chosen randomly and on the basis of their glazing methods (cementation and efflorescence). The Middle Kingdom samples consisted of two beads produced by the cementation process and two produced by efflorescence. The Second Intermediate Period beads were both cementation glazed as there was none of the other production methods present in the assemblage. The selected New Kingdom beads comprised two produced by

cementation and two by efflorescence. Each experiment will be presented below individually, along with the underlying reasons for it being conducted, as well as the results. In Chapter 7 these results will then be compared of to similar experiments undertaken on faience replicas.

5.4.1.1 ELEMENTAL MAPPING

Elemental mapping is not new to faience analysis, however it has rarely been discussed as a useful tool for determining glazing methods. The theory behind the undertaking of this analysis was to test how copper migrated through the faience material, as has been suggested by previous researchers (Tite and Shortland 2008). The premise is that if cementation glazing was used, then the copper would only be present in the glaze and down to the interparticle glass, because it would have had to penetrate the surface of the faience object, but would not have reached the core. However, with efflorescence glazing the copper would be present throughout the body of the faience object, as it had to migrate from the core to the exterior.

The elemental mapping was conducted after the usual procedures mentioned in Section 5.3.2. The SEM was warmed up and the Corning A standard was analysed. However, this method is semi-quantitative and only visually represents the compositional data. The selected sample was then located in the resin block using SEI, before switching over to BEI to get a high definition image at a magnification of x35. Once the image was taken, the elemental mapping was selected with silica, oxygen, copper, iron, manganese, sodium, potassium, and calcium selected as the elements to be analysed. The resulting images (whole bead and a close up) were then made into RGB composite maps of silica (red), copper (green), and iron (blue) together, to illustrate the distribution of copper within the silica matrix and the distribution of iron at the same time.

Middle Kingdom beads 2130-2 and 9384-1 are both cementation-glazed beads, which, when initially inspected, appeared to have copper throughout (Figure 5.3 and Figure 5.4). However, when presented with the half bead image (magnification at x100) the copper is clearly on the surface of the beads and throughout the interparticle glass, yet it is not as apparent throughout the core.

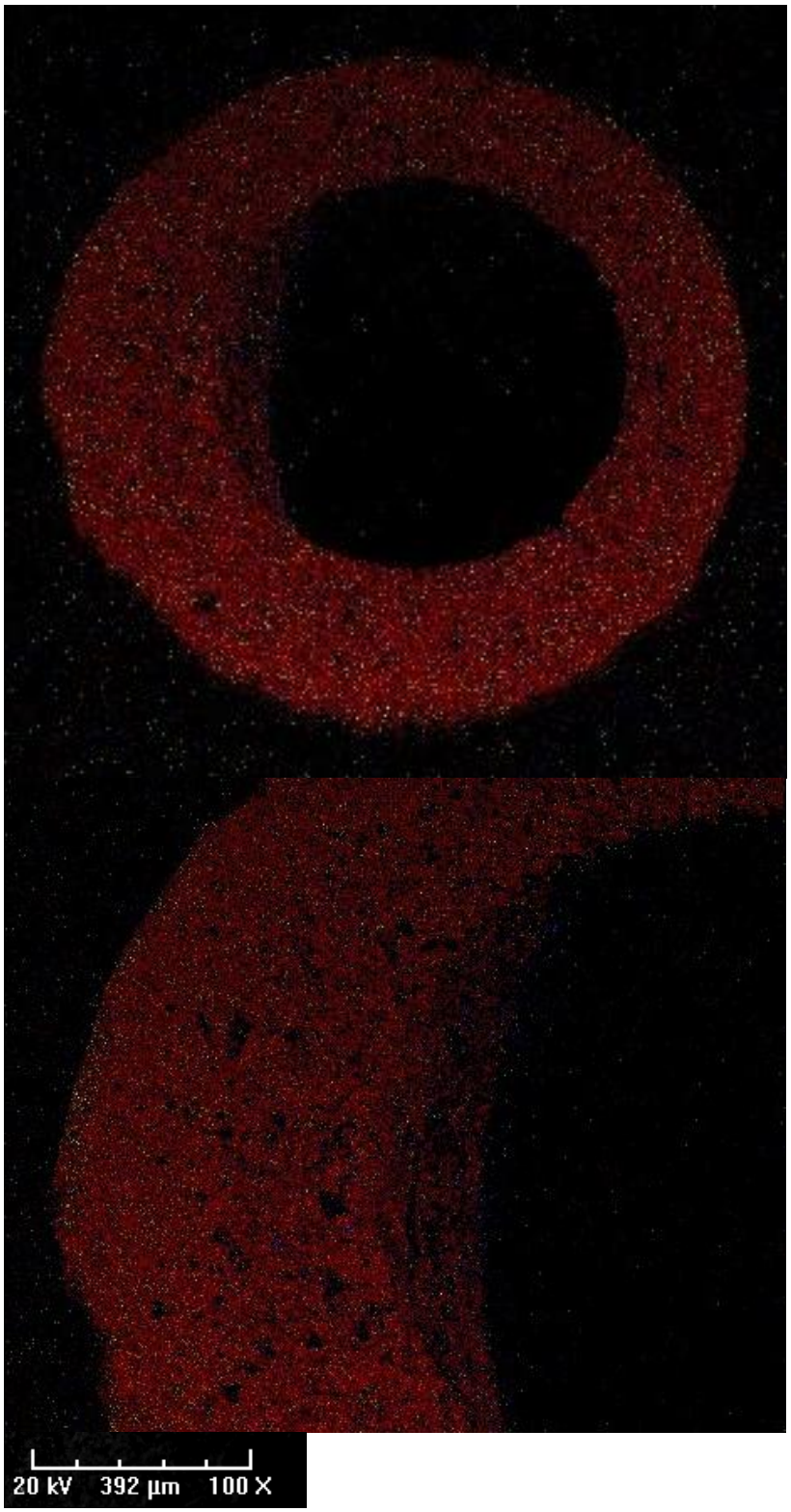


Figure 5.3: Elemental map of bead 2130-2, whole bead and in section. The copper is more apparent in the glaze layer (as greenish-white dots).

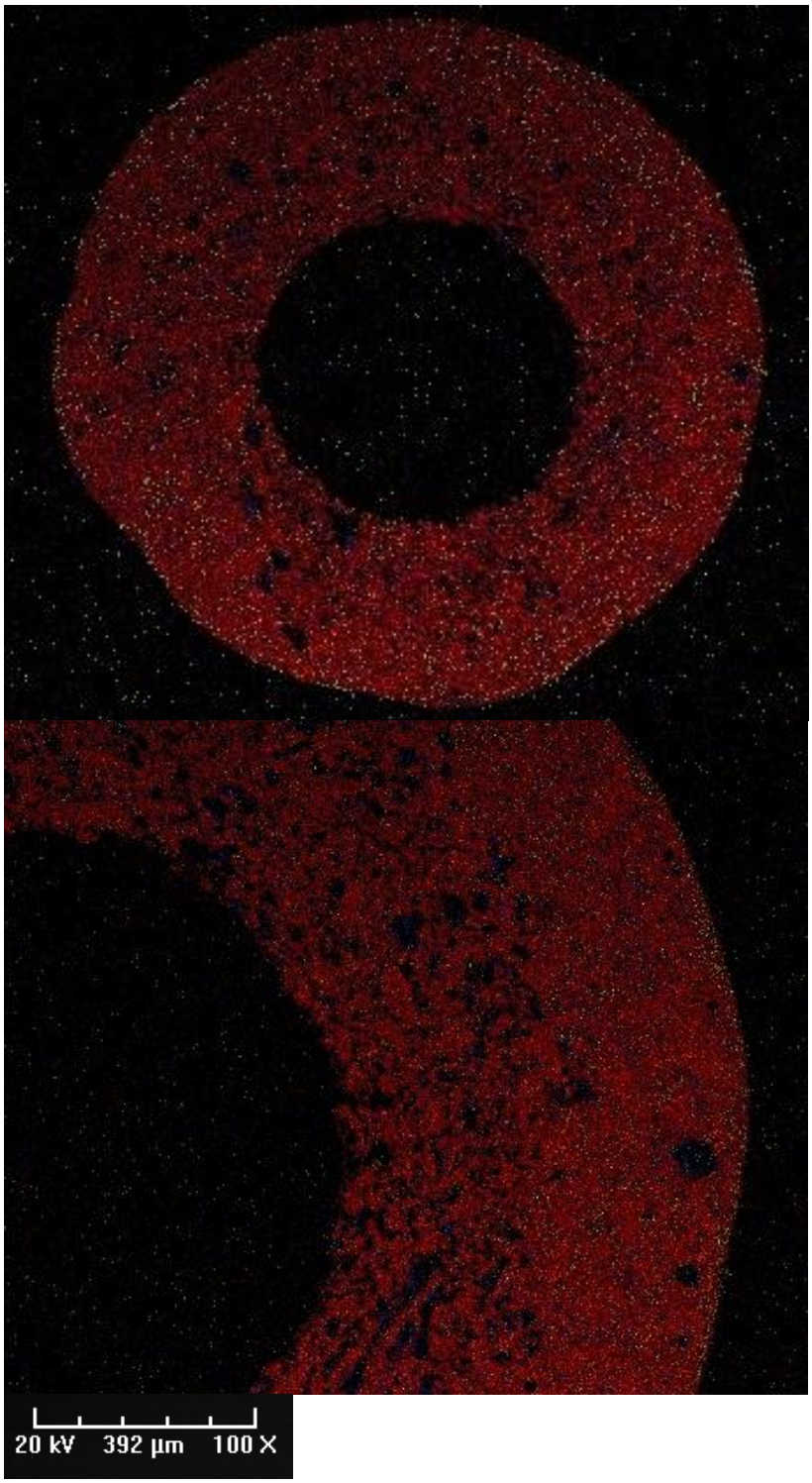


Figure 5.4: Bead 9384-1 elemental map of the whole bead and in section. The copper is more apparent in the glaze layer (as greenish-white dots).

The Middle Kingdom beads 2379-5 and 2383-2 were both glazed by efflorescence. The copper in bead 2379-5 is evenly distributed throughout the bead, as seen in both images (with Figure 5.5 showing the half bead taken at a magnification of x100). However, as expected, the copper is much more abundant

on the external surfaces. Bead 2383-2 is similar to 2379-5 with the copper throughout, but much more obvious on the external surfaces (Figure 5.6 magnification at x75). Interestingly, for both of the beads, the copper is present in high quantities at both external and internal surfaces. This is an excellent indicator of efflorescence glazing, since the copper would migrate to both surfaces.

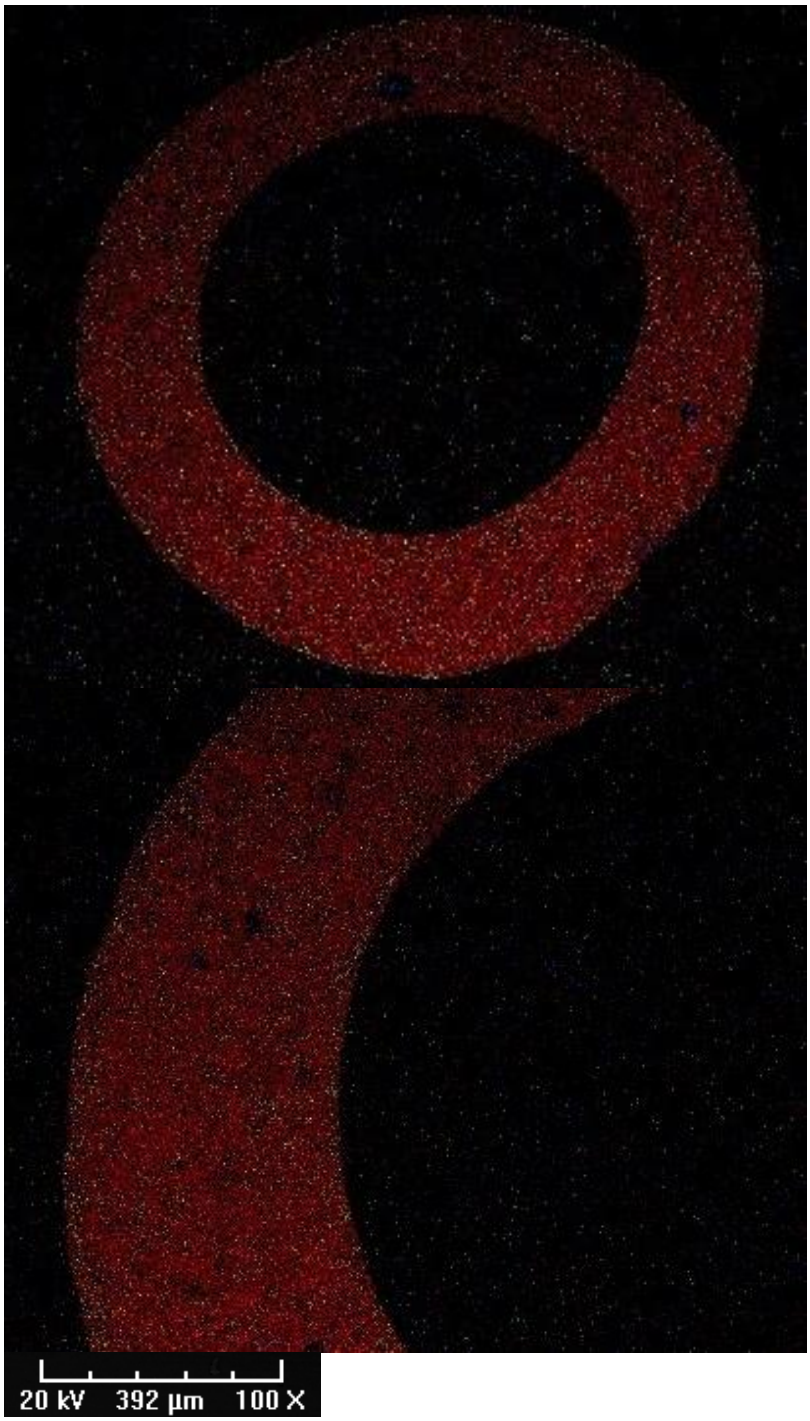


Figure 5.5: Image of bead 2379-5 whole and close up. The copper is present throughout the three layers but more abundant on the surface (as greenish-white dots).

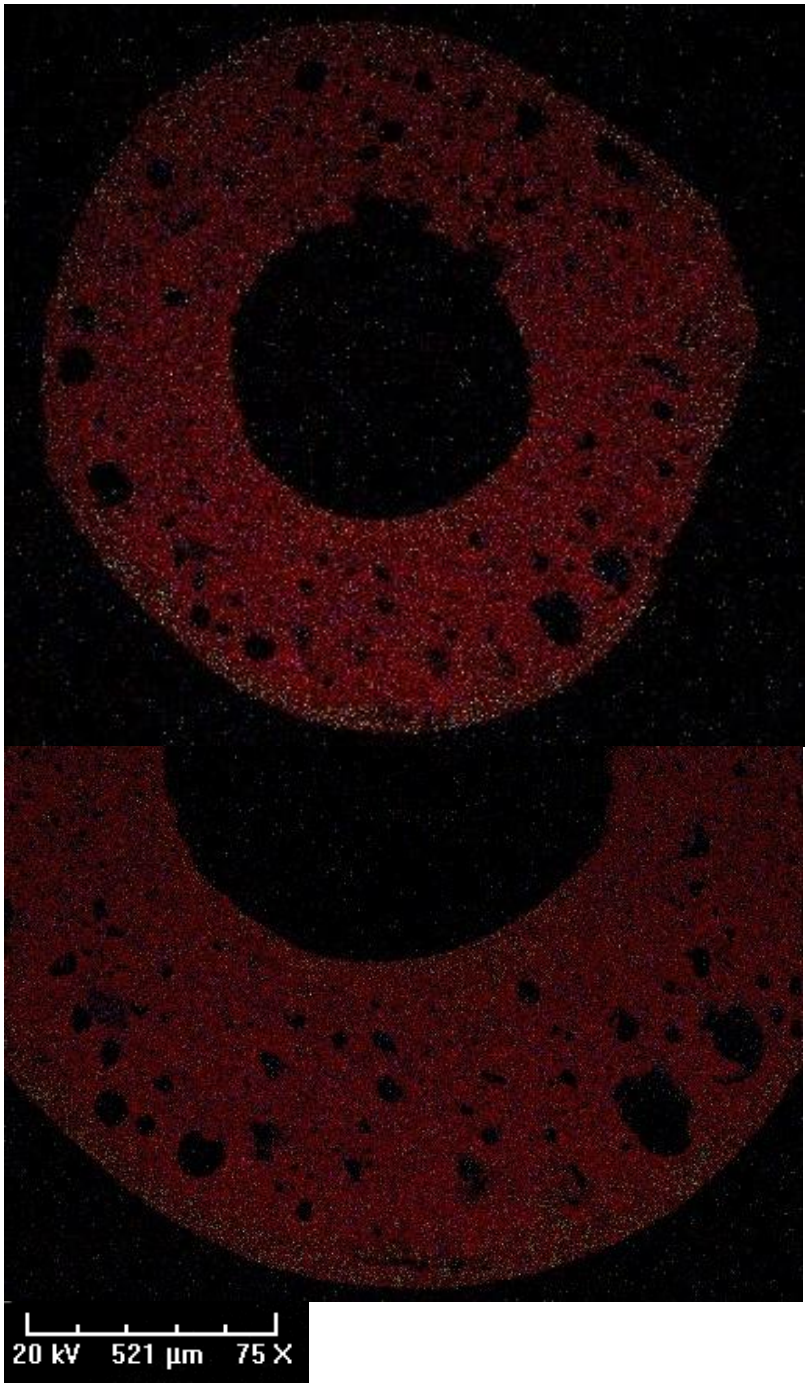


Figure 5.6: Elemental map of bead 2383-2. The copper is present throughout the three layers but more abundant on the surface (as greenish-white dots).

The Second Intermediate Period beads 2385-3 and 2385-6 were both glazed by the cementation method. The copper is apparent throughout, very random in distribution, yet more abundant on the exterior of the bead (Figure 5.7 and Figure 5.8). The complete beads were imaged and elementally mapped at a magnification of x35, while the half beads were analysed at a magnification of x75.

With regard to the glazing method, the New Kingdom beads are very similar to those from the Middle Kingdom. The cementation beads 2375-1 and 2384-7 both have copper on the exterior in higher quantities than in the interior. The copper is very much associated with the interparticle glass (Figure 5.9 and 5.10). The close-up images (magnification of 100 for bead 2375-1 and 50 for bead 2384-7) show the copper distribution clearly. The beads glazed by efflorescence from the New Kingdom (2375-10 and 2380-4) are also similar to the Middle Kingdom beads. The copper seems to be distributed throughout the beads (Figure 5.11 and Figure 5.12).

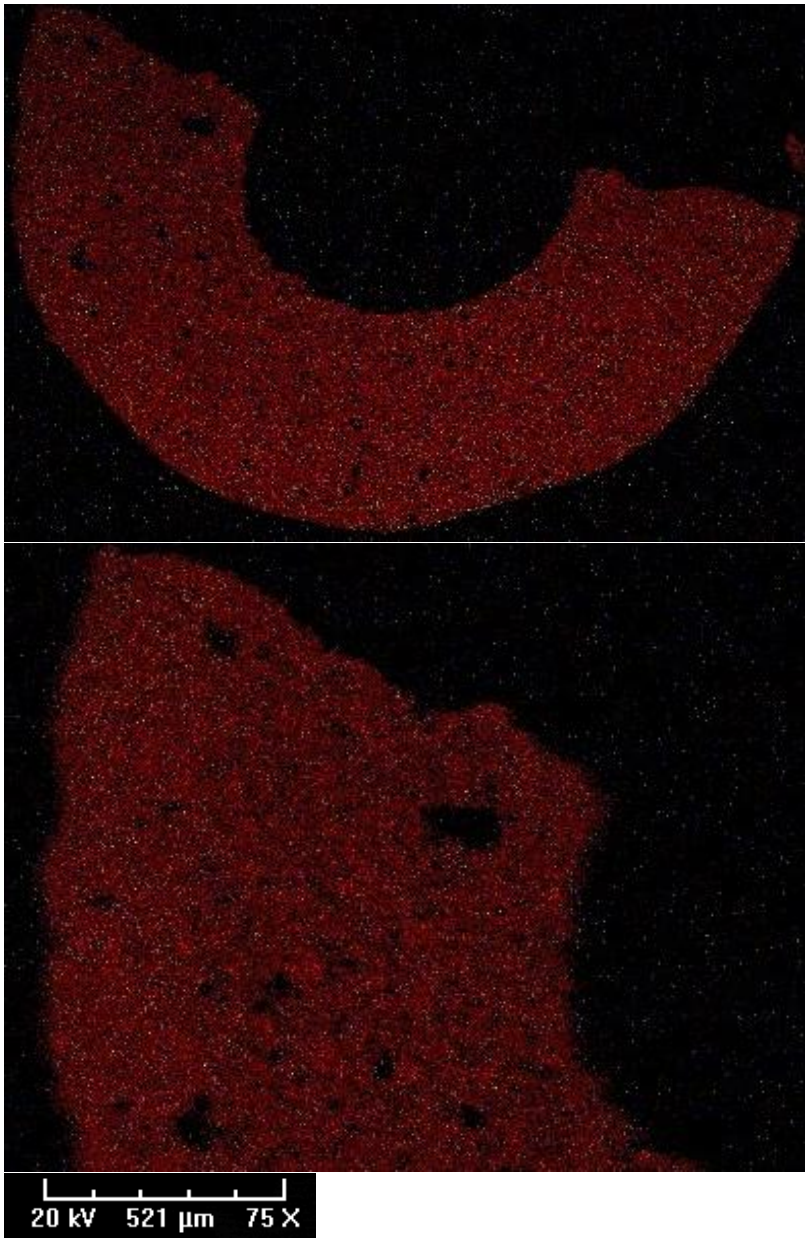


Figure 5.7: Bead 2385-3 elemental map of the whole bead and in section. The copper is more apparent in the glaze and interparticle layer (as greenish-white dots).

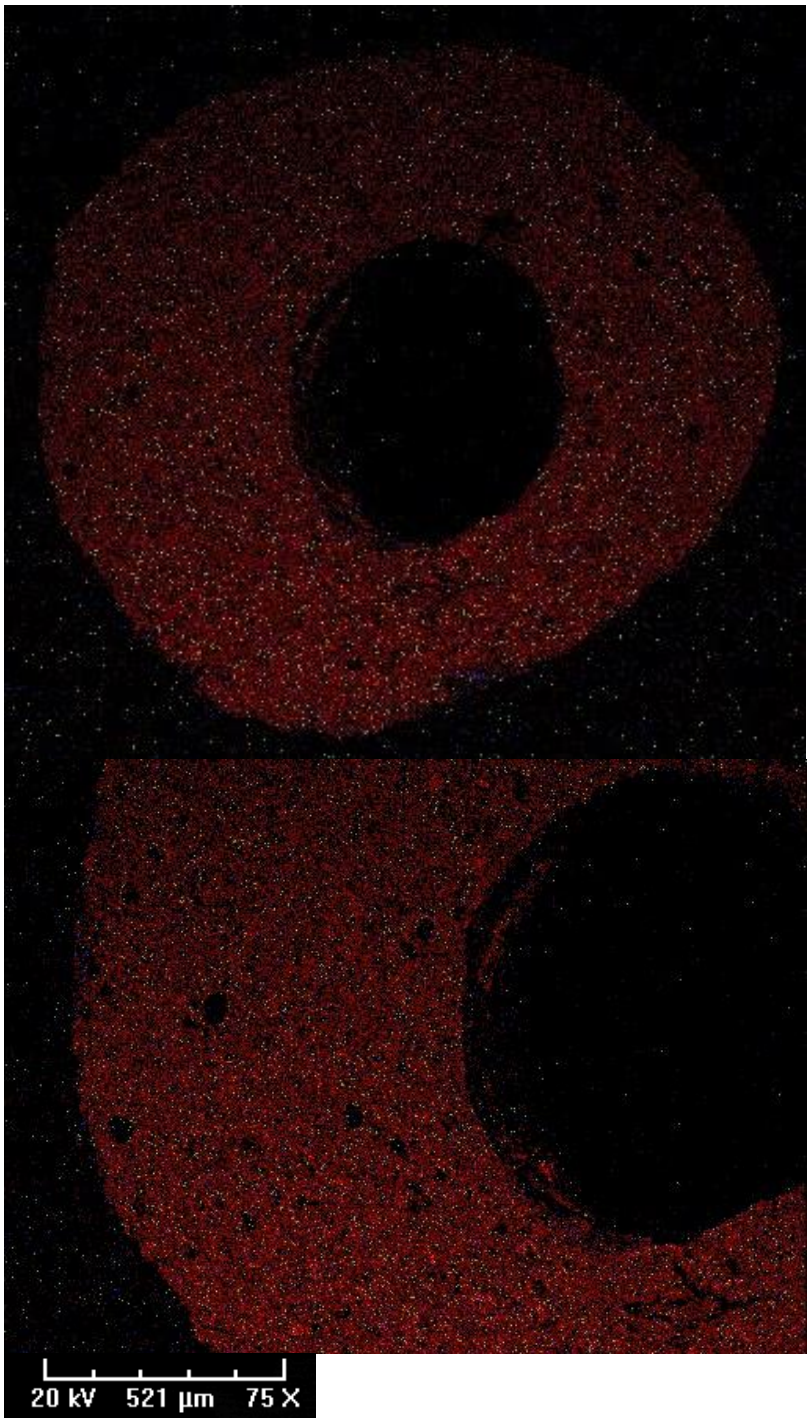


Figure 5.8: Image of bead 2385-6 close up and in section. The copper is more apparent in the glaze and interparticle layer but found throughout (as greenish-white dots).

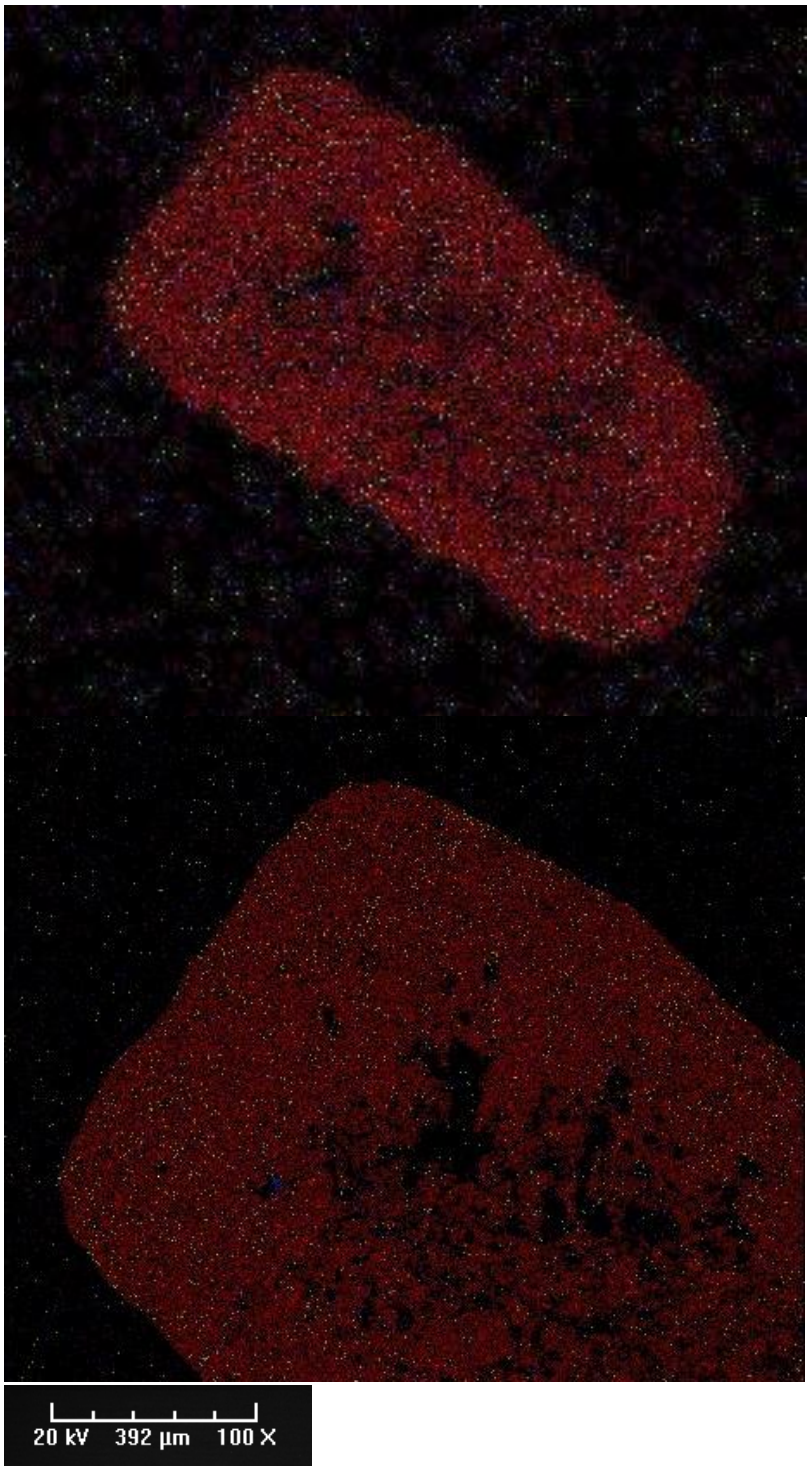


Figure 5.9: Elemental map of bead 2375-1 of the whole bead and in section. The copper is apparent throughout (as greenish-white dots).

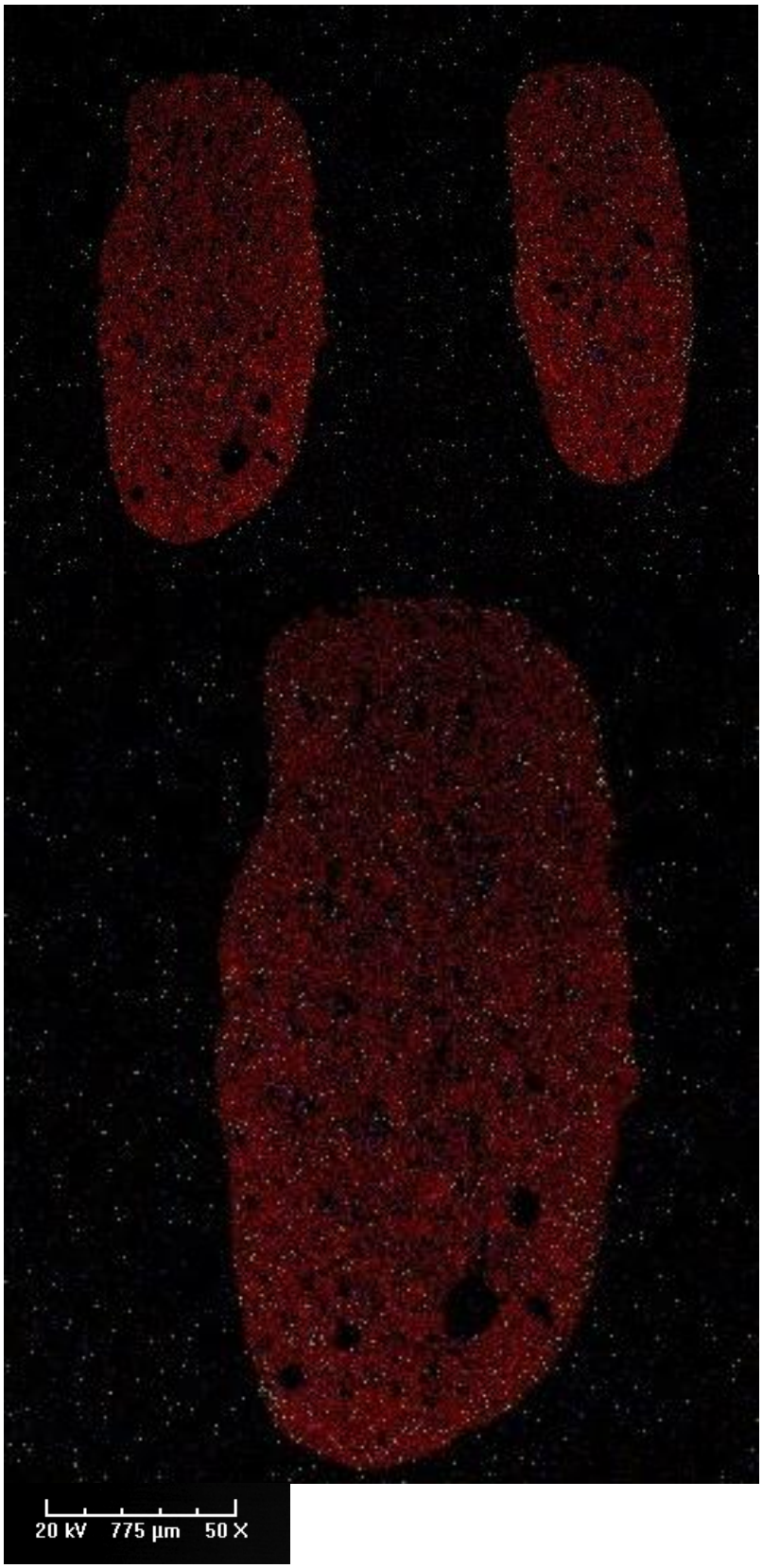


Figure 5.10: Bead 2384-7 elemental map of the whole bead and in section. The copper is present throughout but more apparent in the glaze and interparticle layer (as greenish-white dots).

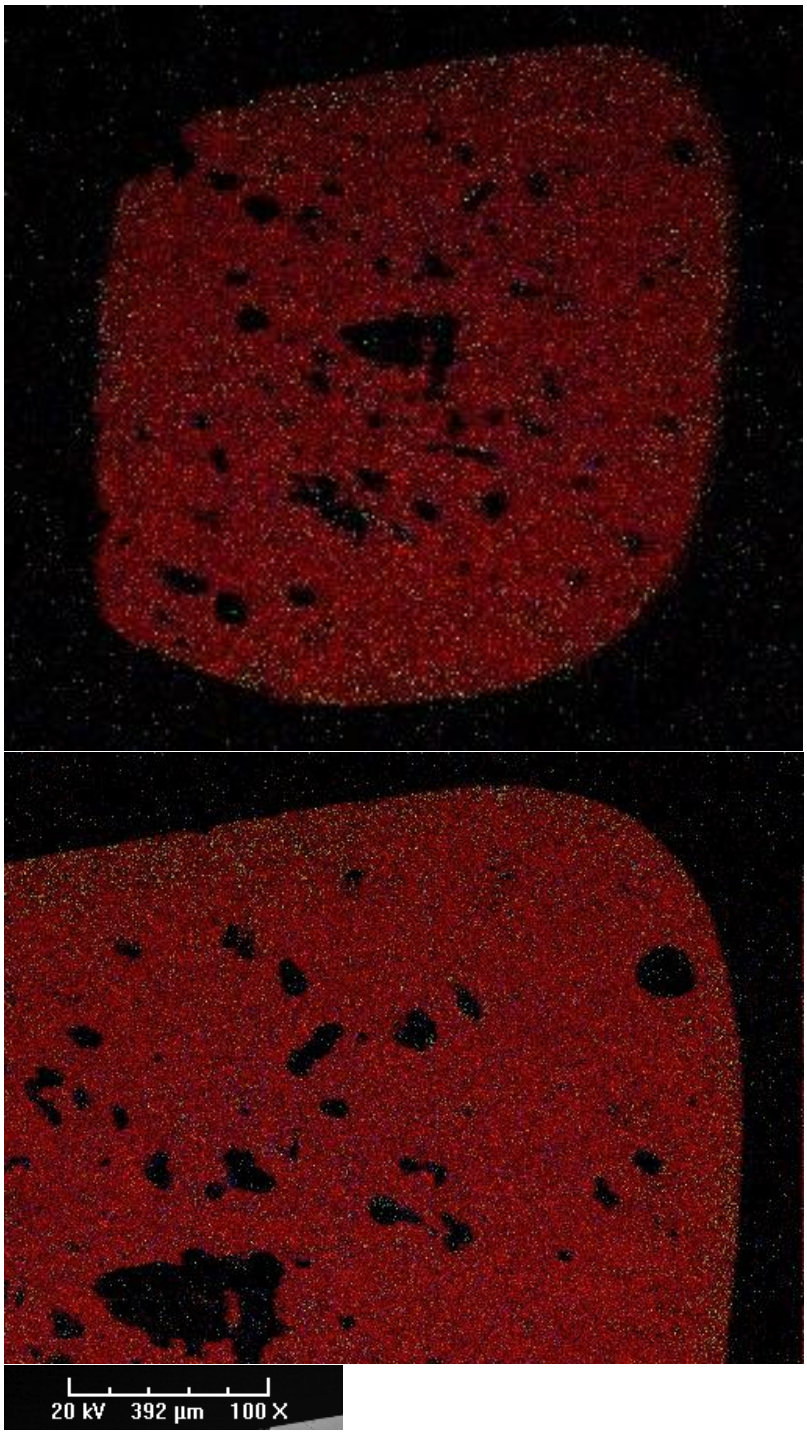


Figure 5.11: Images of bead 2375-10 of the whole bead and in section. The copper is more apparent in the glaze and interparticle layer (as greenish-white dots).

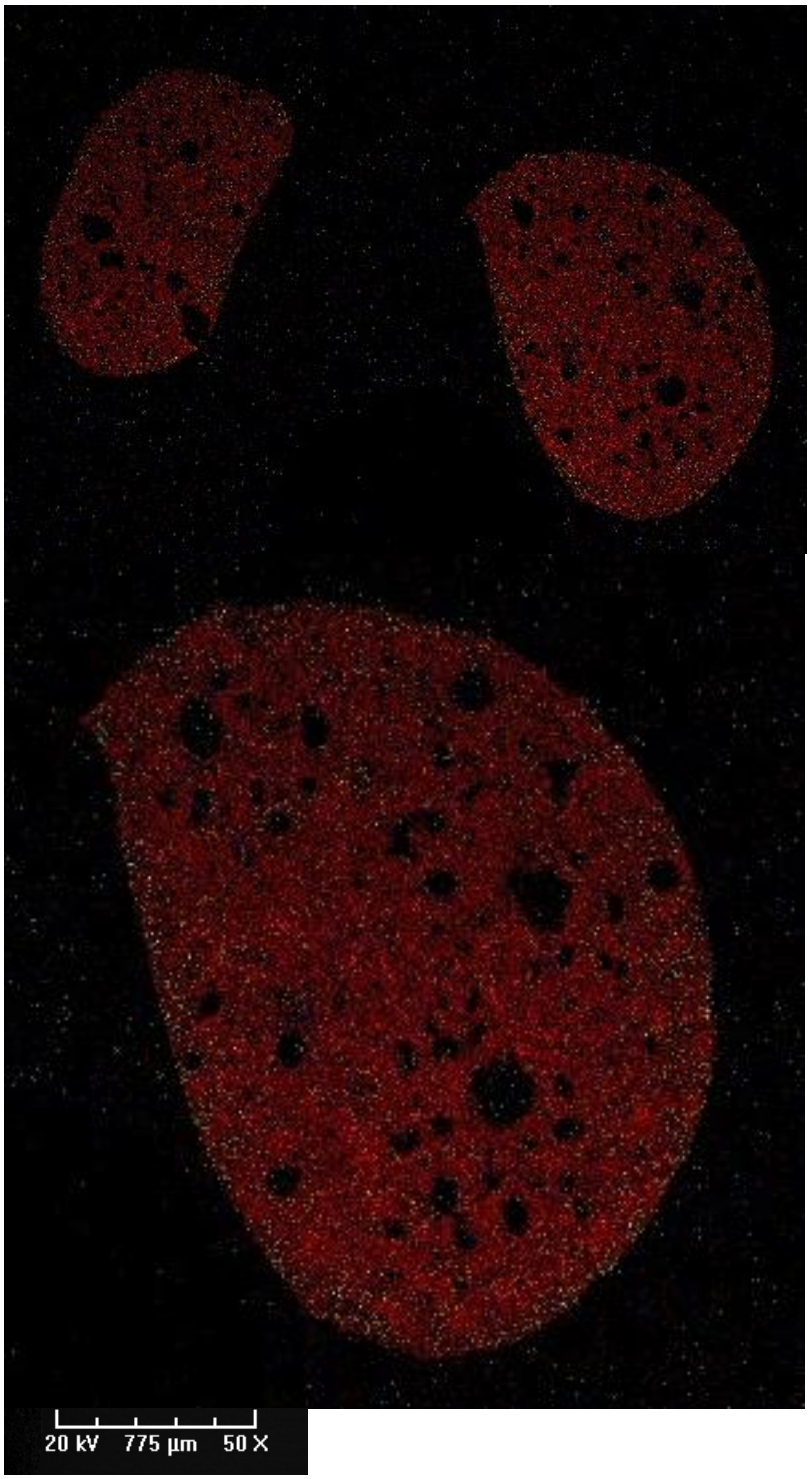


Figure 5.12: Bead 2380-4 elemental map of the whole bead and in section. The copper is more apparent in the glaze and interparticle layer (as greenish-white dots).

The conclusion resulting from this experiment is that elemental mapping, and the resulting composite maps, are excellent tools for determining the glazing method used for copper-pigmented beads based on the distribution of copper. If the copper is distributed mostly within the interparticle glass and abundant in the glazed

surface, then cementation glazing was the production method used. If the copper is distributed throughout the faience bead with an increase at the glazed surfaces (both interior/perforation and exterior) then the glazing method was efflorescence. The only variation on this was represented by the Second Intermediate Period beads. The copper in these beads was very random and is possibly due to the unique type of bead analysed, as both seem to be made of an unreacted mineral, Wollastonite due to the compositional similarity with the Wollastonite mineral standard utilised for calibrating the SEM-EDS this will be discussed further in the following sections (see specifically Section 5.4.3.2).

5.4.1.2 LINE ANALYSIS

The second experiment conducted on the same faience beads was line analysis. This method of analysis was undertaken to determine whether the surface of the faience material was representative of the whole artefact. There has been extensive research conducted on the surface of faience material, yet it has always been regarded as a multi-layer artefact, which would suggest that this research should only be used when trying to interpret glazes. The method was also conducted to show if there was weathering of the glaze layer, causing surface alterations (Romich 1999: 5). This would be determined if the quantity of copper was higher inside the glazed layer than on the surface.

This method of analysis was conducted by obtaining a high definition BSI picture on the SEM, with a scan size of 1024 and the magnification varying from x35 to x50. Once this image was acquired it was then annotated with a line across the area selected for analysis. This line was usually from the glazed surface to the core of the bead. The number of points was set to 130, with fixed distances, for 300 seconds. The elements selected for analysis were silica, copper, and iron, to be consistent with the elemental mapping selection. The data obtained from the line analysis was then overlaid on the BEI image to depict the data with its corresponding sample area.

The cementation-glazed Middle Kingdom beads were very similar to each other, in that the copper signal was strongest at the surface of the bead and gradually decreased towards the core. There does not seem to be any significant weathering of bead 2130-2 (Figure 5.13), as the strongest copper signal is at the very surface of the bead. The same can be said for bead 9384-1 (Figure 5.14). However, in the case of two efflorescence-glazed beads (2379-5 and 2383-2), the copper appeared to be abundant on the surfaces of both (Figure 5.15 and 5.16). This is due to the process of glazing, as there must have been enough airflow to

allow the salts to form on the interior of the perforation. Both beads seem to have survived any possible weathering intact. The copper is still more abundant at the surface than in the interparticle glass, indicating that the surface represents the true value for the faience glaze.

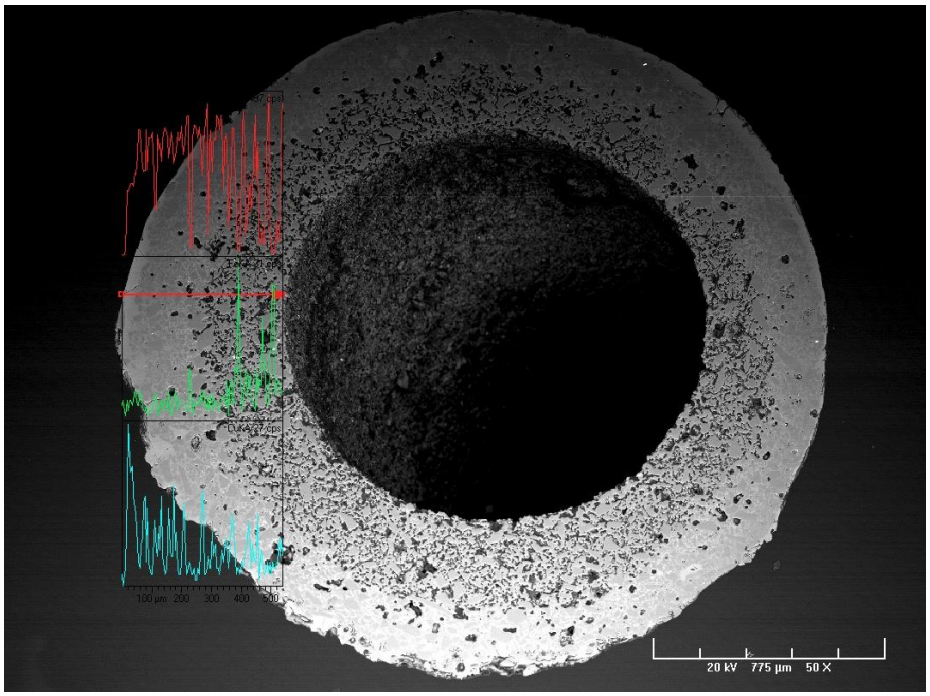


Figure 5.13: Bead 2130-2 copper line analysis displayed in blue, iron is presented as green, and silica is represented in red.

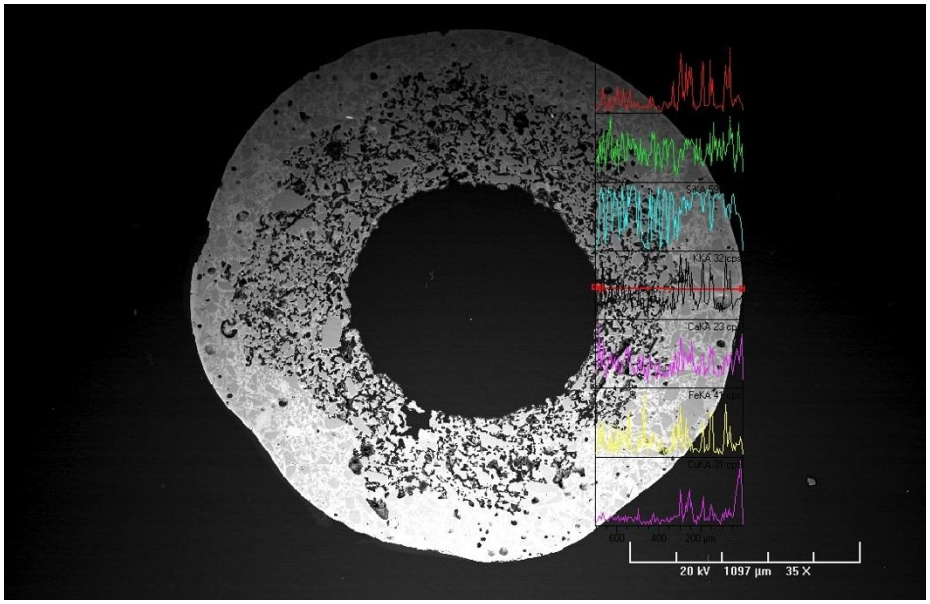


Figure 5.14: Bead 9384-1 the copper is represented as the purple line above the scale, the green line represents aluminium, blue line is silica, black is potassium, light purple is calcium, yellow line is iron, and the red line is sodium.

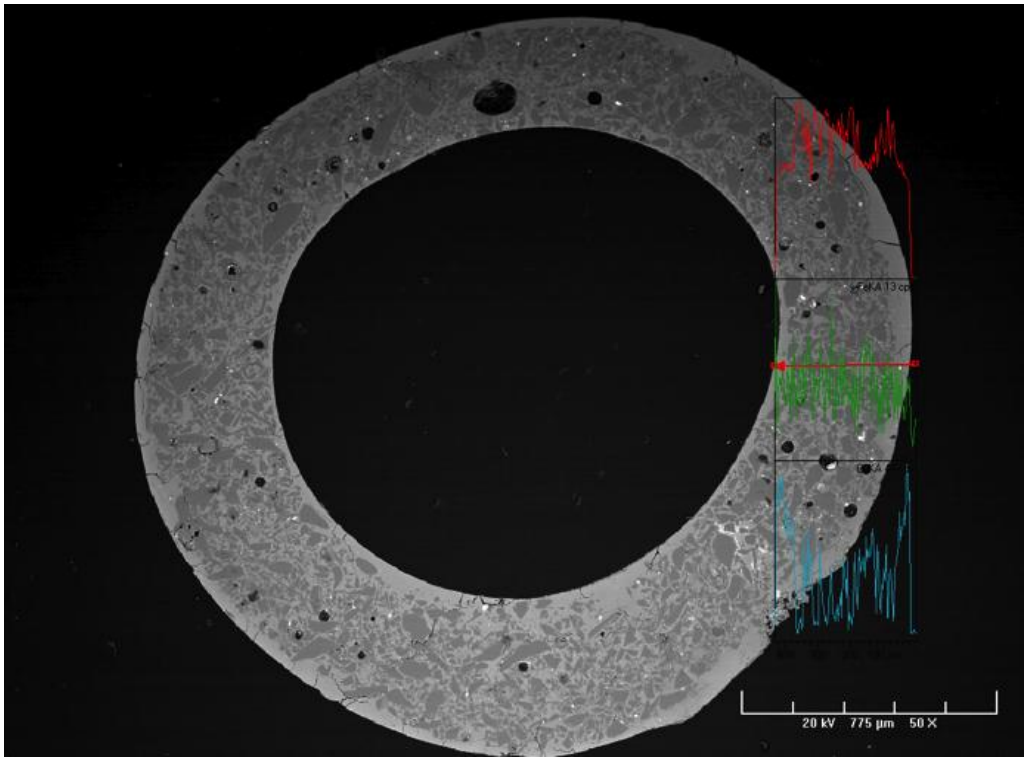


Figure 5.15: Bead 2379-5 the bead copper is represented by the blue line, the green line is iron, and the red line is silica.

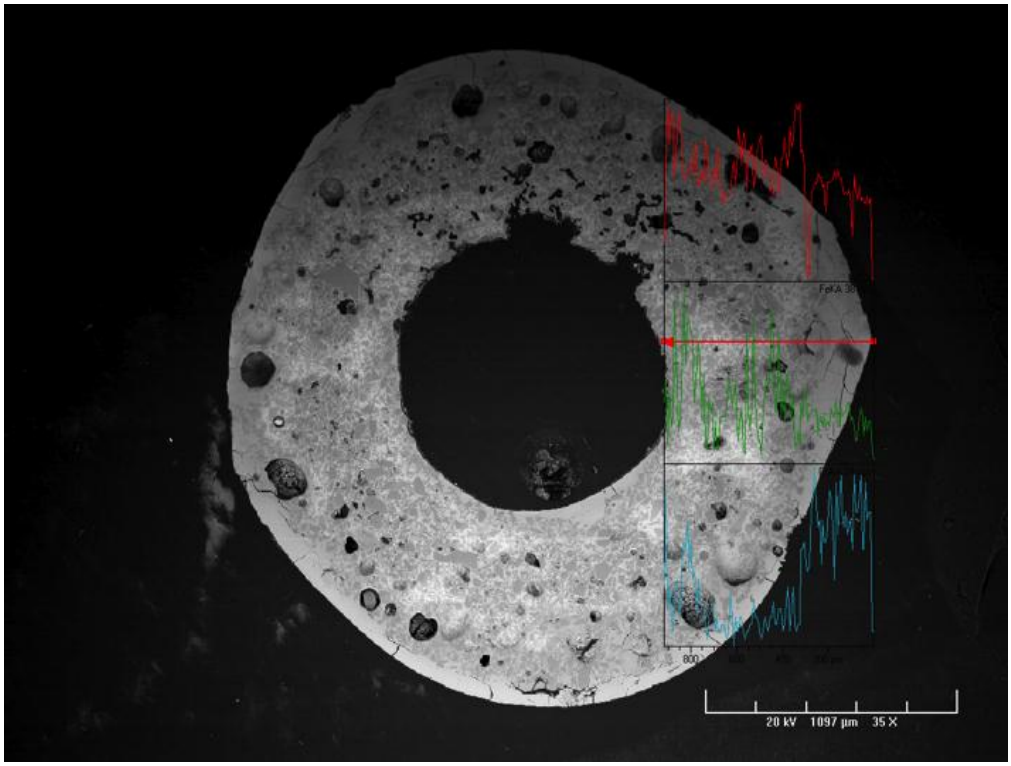


Figure 5.16: Bead 2383-2 the copper represented as the blue line, the green line represents iron, and the silica is presented as red.

The Second Intermediate Period beads analysed were both cementation-glazed. Bead 2385-3 is very similar to the cementation-glazed beads of the Middle Kingdom. The copper signal is very significant at the surface of the bead and slowly decreases towards the core (Figure 5.17). There is possibly some weathering at one edge of the bead where the line runs across diagonally (done in order to incorporate both edges) – this is indicated in the drop in the copper signal/level in this region. Bead 2385-6 falls into the category of cementation glazing (due to a lack of interparticle glass), however this bead is possibly Wollastonite and is simply an unreacted mineral. The copper was apparent throughout the bead, and there was no glaze or interparticle layer to give any indication of weathering (Figure 5.18).

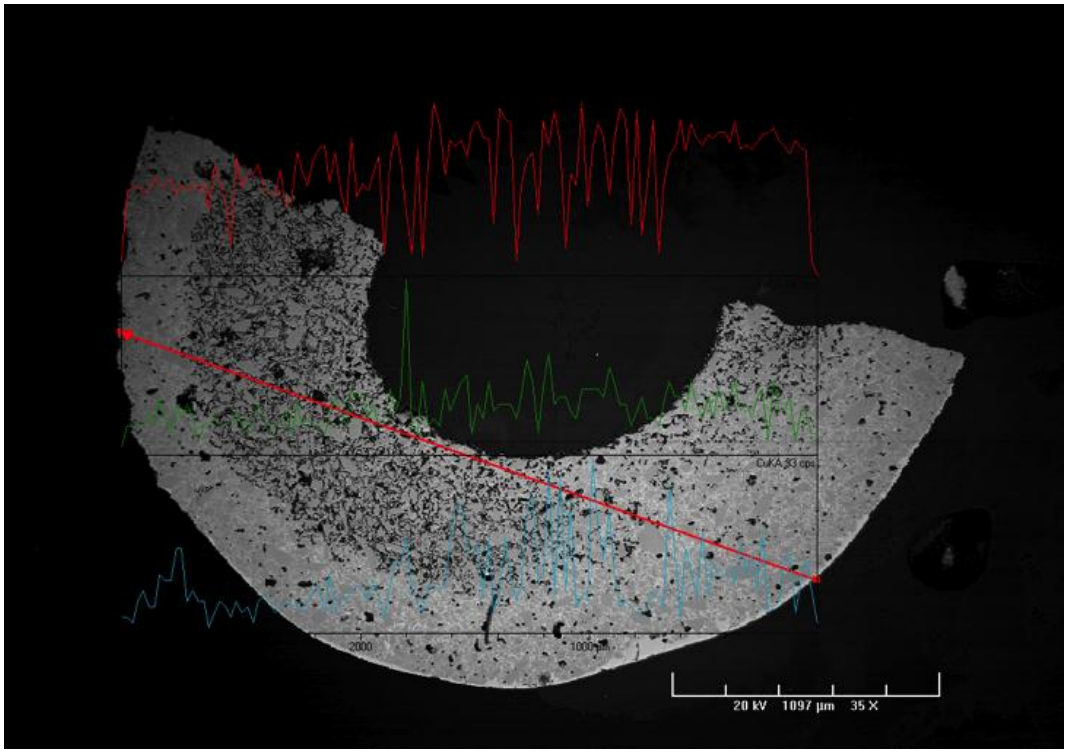


Figure 5.17: Bead 2385-3 the copper line is represented in blue, the green line is iron, and the red line is silica.

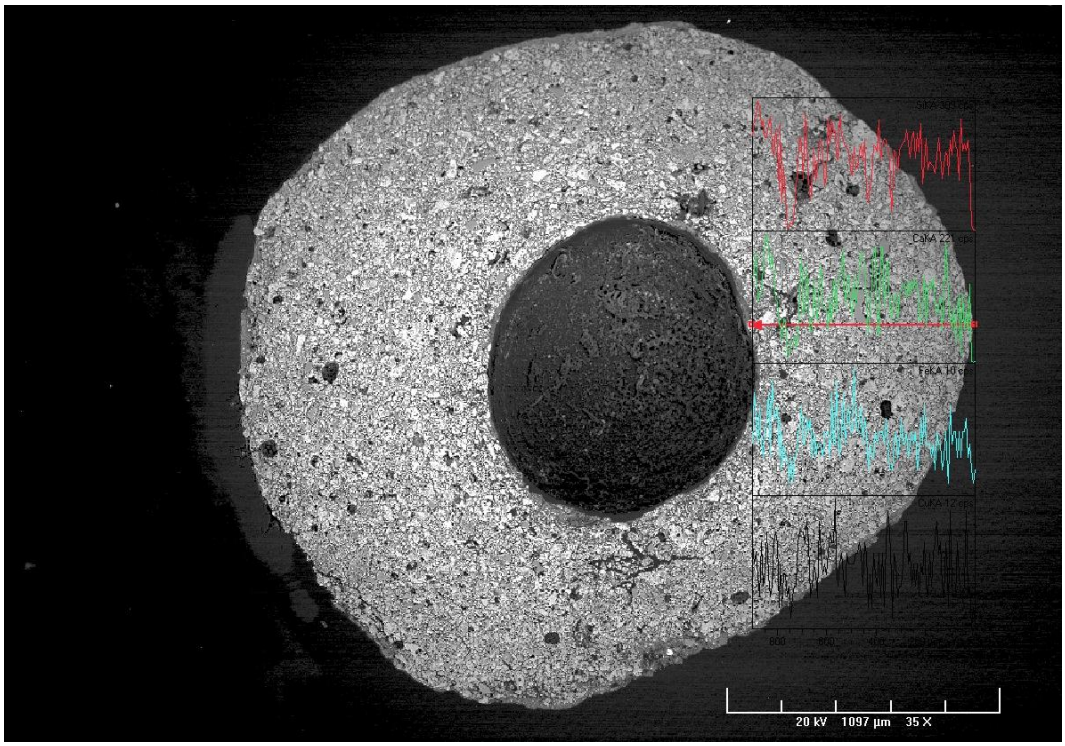


Figure 5.18: Bead 2385-6 the copper represented by the black line at the bottom, the red line presents the silica, the green line is calcium, and the blue line is iron.

The New Kingdom beads are once again similar to the Middle Kingdom ones. The cementation-glazed beads (2375-1 and 2384-7) are particularly similar to each other in that the copper signal was strongest at the surface of the bead and slowly decreased towards the core. This can be explained by the silica particles and voids in the core (Figure 5.19 and 5.20). Neither beads displays any signs of weathering. The copper seems to be consistently on the exterior of the beads in large amounts.

With the efflorescence-glazed beads (2375-10 and 2380-4), copper appears to be abundant at both surfaces (Figure 5.21 and 5.22). However, the copper is also plentiful in the core of the faience bead due to the extensive interparticle glass. This is due to the process of glazing. Bead 2375-10 does not seem to have suffered from weathering. On the other hand bead 2380-4 might display signs of weathering due to the lack of glaze on one end of the bead.

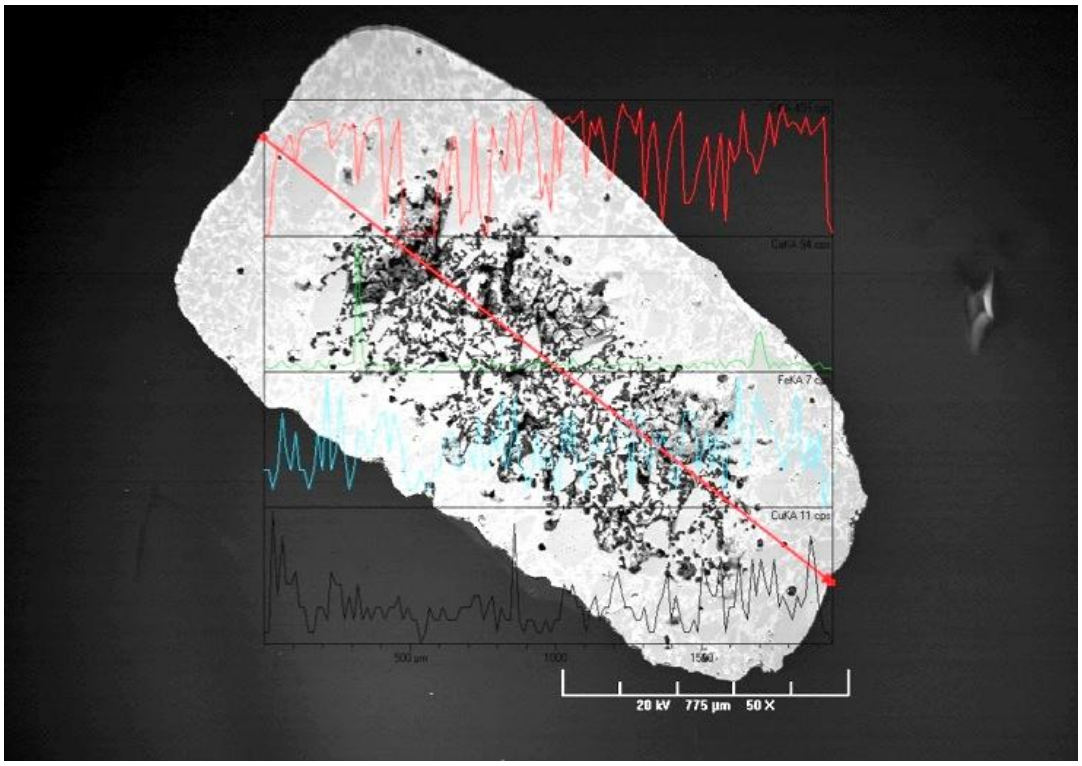


Figure 5.19: Bead 2375-1 the copper is represented by the black line, the red line presents the silica composition, the green line is calcium, and the blue line is iron.

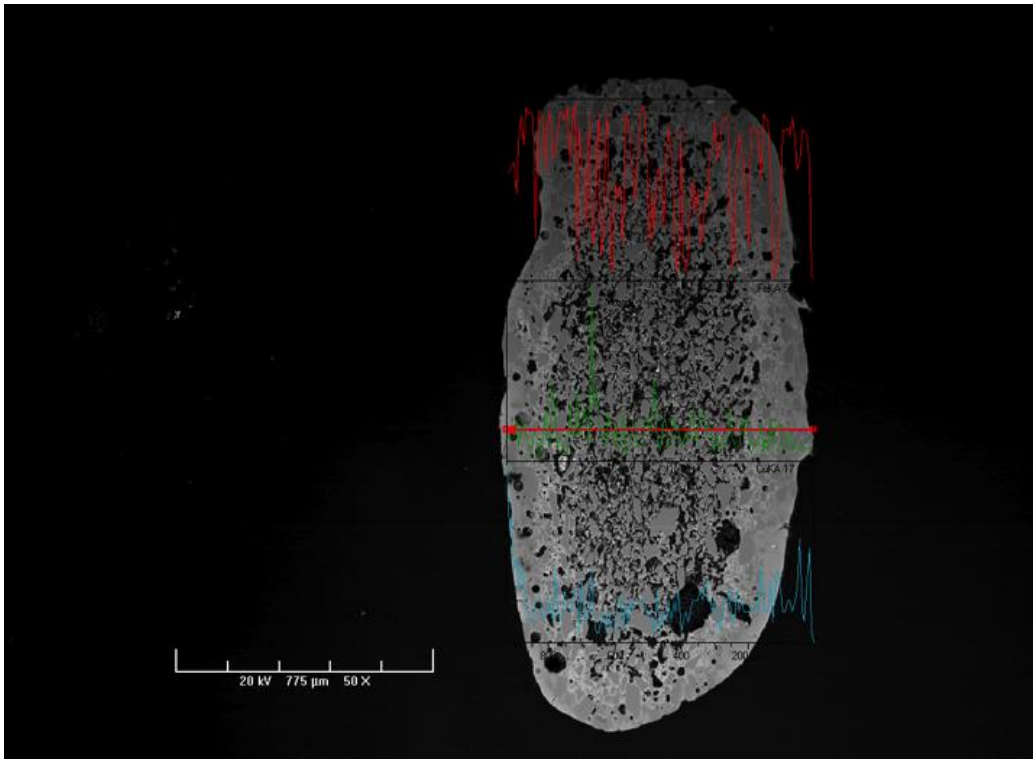


Figure 5.20: Bead 2384-7 the copper is represented by the blue line, the green line is calcium and the red line is silica.

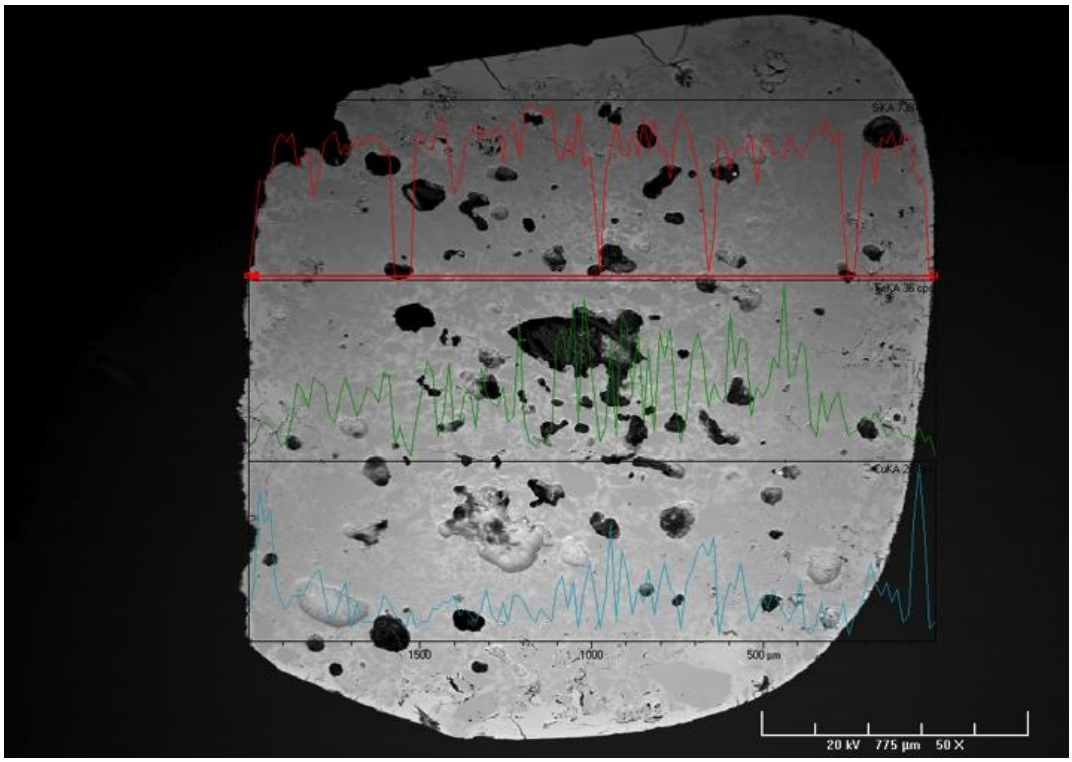


Figure 5.21: Bead 2375-10 the copper line is depicted by the blue colour, the red line is silica, and the green line is iron.

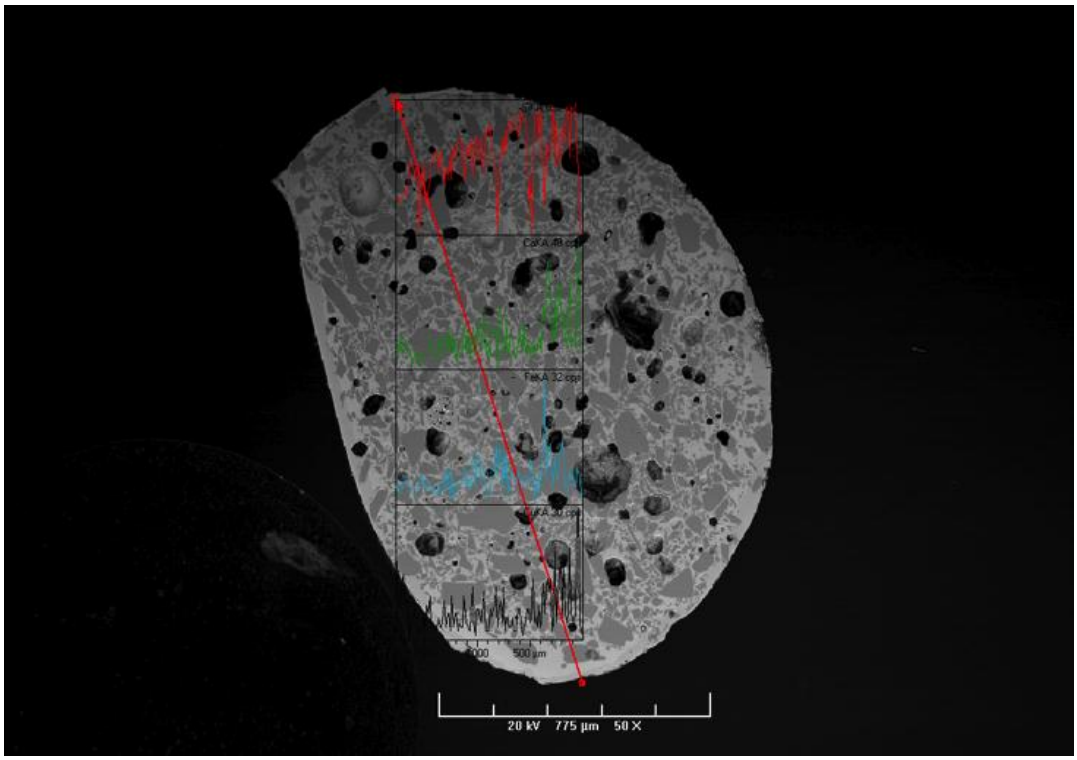


Figure 5.22: Bead 2380-4 the copper is represented by the black line, silica is presented in red, calcium is green, and iron is blue.

The results from this experiment suggest that surface analysis is representative of the glazed layer only, due to the changes between the three faience layers. Depending on the glazing method, the copper level drops in the core layer, whereas the surface is copper-rich. This is by no means a surprise; this part of the research was conducted in order to prove scientifically what had already been suggested (Tite and Shortland 2008). Also, this method was utilised to determine weathering of the faience material at the surface. The premise was that if there had been weathering, the interparticle glass would contain more copper. This was not necessarily true, and this needs to be researched further. After all, it is difficult to determine the original thickness of the glaze. This method is very similar to the elemental mapping analysis, as it mapped the location of copper within the bead.

5.4.2 Production Methods: Glaze

This research set out to determine if faience technology changed from one period to the next. One of the most significant questions that needed to be addressed was whether or not the glazing methods changed over time. As mentioned earlier, the SEM analysis was conducted in order to determine the glazing method, and distinguish any morphological features that could aid in the identification and characterisation of production methods. The glazing method was determined on the basis of the backscatter images, which present the different phases of faience in greyscale based, both on the elements present and on their atomic number. The silica-rich core appears darker in comparison to the copper-rich glass phases (interparticle glass, and glaze) of the faience material (Tite *et al*. 1983: 26). In viewing and comparing the silica to the glass phases, it is easier to determine where one begins and the other ends. The glazing method can be identified by the amount of interparticle glass present throughout the faience artefact. If there is extensive interparticle glass, then the bead was glazed by efflorescence. If there is very little interparticle glass (especially in the core) the method of glazing was cementation (Peltenburg 1987: 10, Tite *et al.* 1987: 128). The application glazing method also has very little interparticle glass present.

In the past, several researchers have stated that glazing methods are associated with the chronology and technological development of faience (Nicholson 2009: 5-7, Nicholson and Peltenburg 2000:181-184, Vandiver 1982: 172). This theory started with Vandiver's (1982) work on faience with a binocular microscope and some limited work with SEM, and suggested a certain criteria on the basis of which the three different glazing methods could be distinguished over time. Such conclusions were based on the perception that there was a lack of cementation

glazing before the Middle Kingdom and then also a lack of its usage during the New Kingdom. Efflorescence was supposed to have been used throughout the Middle and New Kingdom yet not in the Second Intermediate Period, while application glazing was said to be the predominant glazing method in the Second Intermediate Period, and frequently used in the New Kingdom (See Table 2.1).

However, this research has found that cementation and efflorescence were the predominant glazing methods used throughout *all* the time periods in question with only one case of application glaze being observed. Only one bead (9384-10) out of the whole assemblage falls into the category of application glaze, as it is a stone bead. On cursory examination this bead does look like faience, and it is recorded in the museum catalogues as such.

The SEM images of each bead can be found in Appendix F. However, the glazing determinations that are based on the SEM images can be found in tabular form with all the other bead information in Appendix A or as a summary in Appendix H. At this point, a comment on the SEM images should be made, particularly in relation to charging and the fragmentary nature of some of the beads. Several beads charged excessively, no matter how much carbon was used to discourage it; this was due to the very porous nature of these beads. This charging affected some of the SEM images, of which only the best were selected for Appendix F. The beads most affected were 2383-2, 2383-3, 2379-10, 2345-1, 2345-2, and 2345-4. Notice should also be taken of bead 2130-9, which is a fragment of a bead, which because of its very small size, was only subjected to three spot analyses.

5.4.3 Raw Materials

The EDS system aided in the determination of the raw material sources utilised for the production of the faience beads (Verita *et al.* 1994: 241). This was accomplished by the analysis of major, minor, and trace elements present in the beads (Shortland and Eremin 2006: 581). The analysis is very important for determining the presence and quantity of the elements, and thereby characterising the time periods based on compositional variation (Tite 1972: 210). This analysis aims to answer the question in Chapter 1: 'What are the chemical variations taking place from the Middle to the New Kingdom?'

The results and discussion presented in this section are based on the calculated averages of the six spot analyses observed by time period, and are summarised in Appendix H. The raw data is in Appendix G and the BEI images with the spot analysis marked are located in Appendix F. The results are presented by raw material type, possible sources, the method of deciding source used, and visual

representation of the results in scatter plot form. The main components of faience (silica-soda-lime) will be discussed initially, and then the colourant sources and trace elements will be presented in relation to the major elements.

5.4.3.1 SILICA

The silica source for faience can either be sand or crushed quartz as discussed in Chapter 2 (Section 2.1.5). In the past, researchers have designated two different methods for determining which source was used: impurities and particle shape (Robinson *et al.* 2004: 91, Shortland and Eremin 2006: 583). If aluminium, titanium, manganese, and iron are all present in the faience material then they were likely added as an impurity in the sand as these are common impurities in Egyptian sand (Shortland and Tite 2005: 41, Tite *et al.* 2002: 586). However, if manganese is present in large quantities it could be a component of plant ash or deliberately added as a colourant. If iron is present in large quantities, it could have been added deliberately as a colourant (discussed further in Section 5.4.3.4). If there are no impurities present, then the source of silica was crushed quartz pebbles, which are relatively pure and therefore do not add any impurities.

Another means for determining the silica source is the study of the angularity of the particles. It was argued that rounded particles would suggest that sand was the silica source, whereas angular particles would be produced from crushed quartz. This argument was based on the assumption that the action of crushing the quartz would cause sharp breaks, whereas sand would be rounded from natural friction with other sand grains and gradual weathering. However, this form of determining the silica source has been discredited recently because even sand would have required grinding to obtain the fine particle size seen in some of the faience beads, and this would produce angular particles (Tite and Shortland 2008: 38).

The concentration range of silica in the faience, from all periods under investigation, is between 45.81% and 95.28%. These results are well within the expected values for silica in faience, keeping in mind that they are acquired by spot analysis, which attempted to analyse the interparticle glass and not the silica particles themselves. All of the faience beads studied for this thesis were produced with sand as the silica source based on the presence of impurities, such as iron and aluminium, which appear in vast quantities. Figure 5.23 depicts the quantity of silica in comparison to iron, based on time period. The vast majority of the beads fall into a large group at the top of the plot, with high silica and some iron, which would be easily interpreted as a situation in which iron was an impurity in the silica. The beads plotted to the right of those with high iron are actually beads that have iron as their

source of colourant therefore added intentionally (Figure 5.24). The low levels of silica for some of the samples are due to these beads being made of a mineral rather than faience. They are possible Wollastonite beads with a composition of about 60% silica and about 30% calcium (matching the same silica to calcium ratios as the Wollastonite mineral standard used for the SEM-EDS calibration). However, they have a high quantity of copper too, and they will be discussed further in the next section. Figure 5.25 illustrates the presence of aluminium as an impurity related to silica, and falls in line with the other groups present in Figure 5.23. The beads towards the base of the plot are the very same Wollastonite beads, and the ones to the right (although there are less of them) are the beads coloured with iron.

Titanium and manganese are also present, albeit in fewer beads and in lower quantities, making them difficult to depict in a graph. This falls in line with the conclusion of Kaczmarczyk and Hedges (1983: 123) that sand was the silica source for the majority of faience produced in Egypt. This is not surprising, as the site of Abydos has plentiful sources of sand. Just to the southeast of the Egyptian limestone plateau on which the site sits, there are large deposits of Pleistocene white and yellow quartz sand (Snape 1986: 2), a local source that the faience workers could have utilised quite readily.

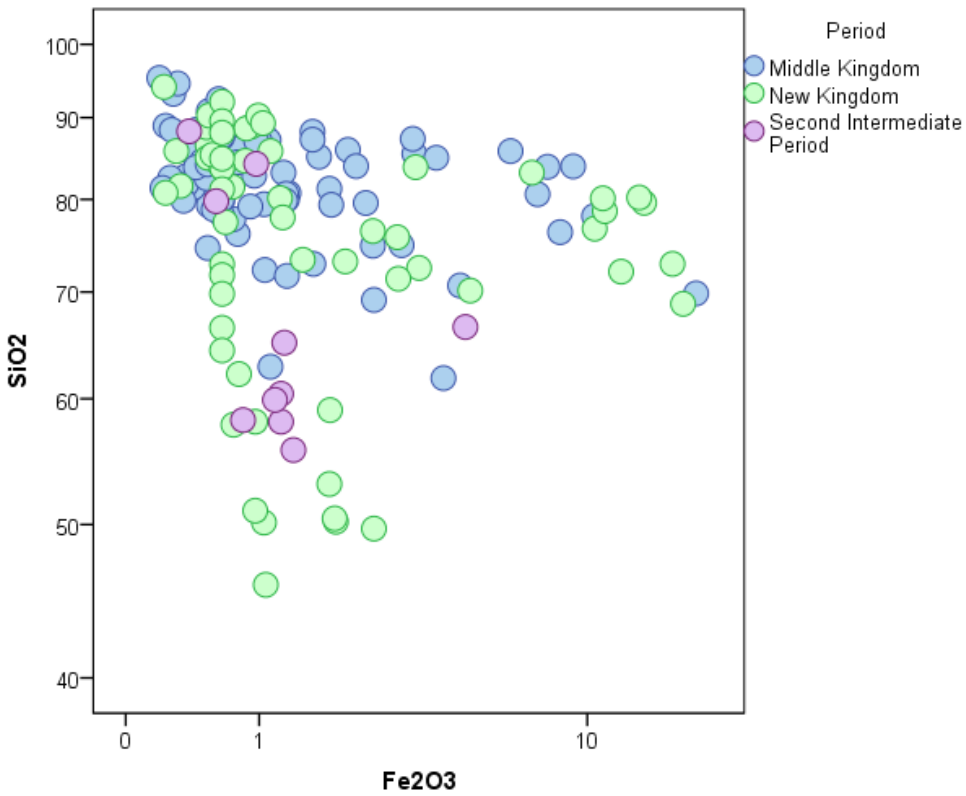


Figure 5.23: Silica percentage in the faience samples in comparison to the iron percentage.

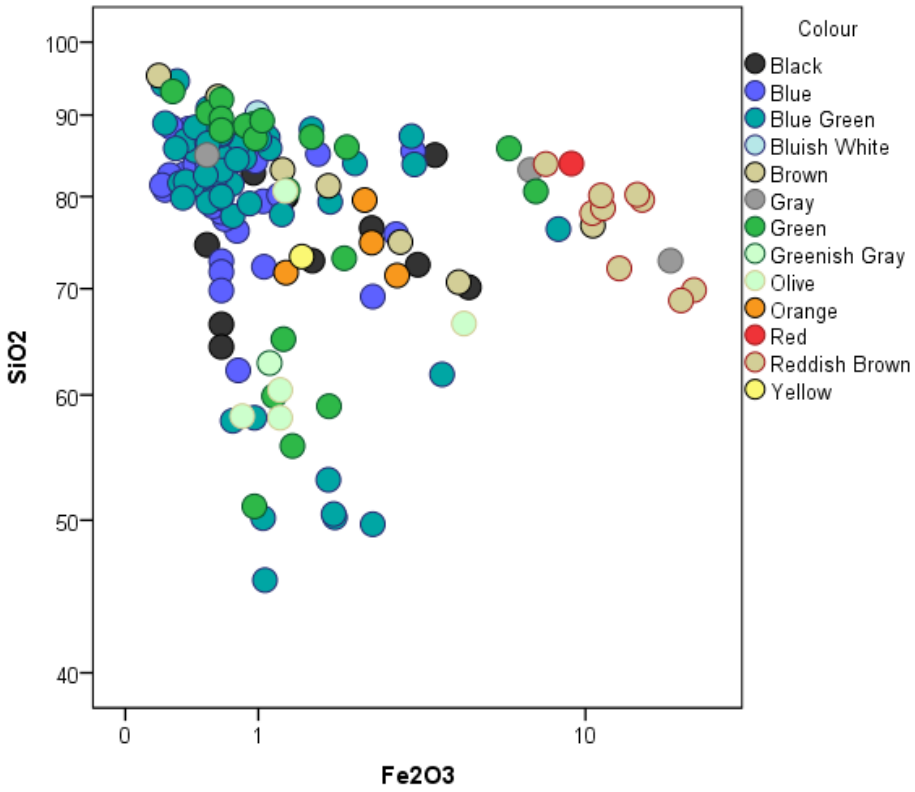


Figure 5.24: Silica percentage in comparison to the iron percentage based on colour.

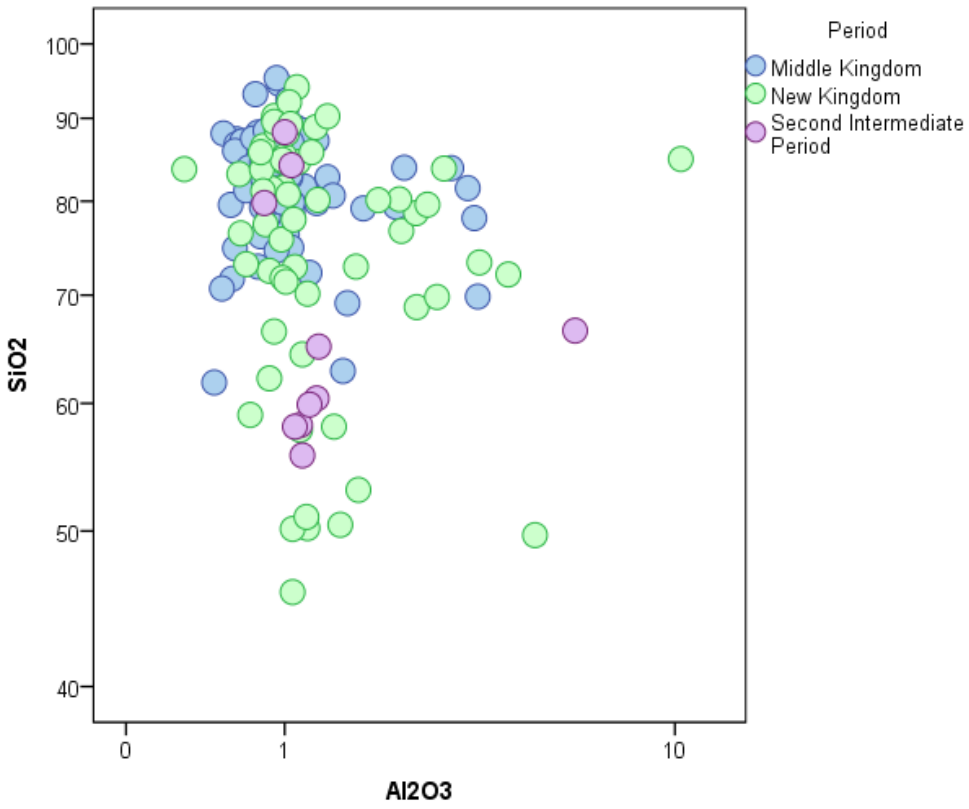


Figure 5.25: Distribution of silica percentage and aluminium percentage by time period.

5.4.3.2 LIME (calcium)

The calcium content of faience is very important because it is a network stabiliser, essential for making the interparticle glass and glaze. There are three possible sources for the lime/calcium content of faience beads: the sand, the alkali, or deliberate addition in the form of shells. It is very difficult to determine if the lime was added deliberately or accidentally as an impurity. All that is known is that it was necessary for faience production, and therefore either had to be added, or the ancient craftsmen must have known that it needed to be present in another ingredient, for example sand in the case of this assemblage. Egyptian sands contain about 2-18% lime, so it stands to reason that the sand could also be the source for the lime component of the faience beads (Tite *et al.* 2002: 586) (Figure 5.26). Upon comparing the potassium result with that of calcium it becomes apparent that there is no correlation between the two, and it would therefore be very difficult to determine if the lime was a component of the plant ash (Figure 5.27).

The average faience bead is said to include from 0.2% to 35.0% calcium, (Kaczmarczyk and Hedges 1983: 22), which is consistent with the results of this research. However, the high peaks of calcium in most of the Second Intermediate Period assemblage and also a few sporadic beads from the Middle and New Kingdom (see Appendix A or H, Column: Glazing Method, for information on specific beads), led to speculation that some of the beads were made of frit rather than faience or Wollastonite (Figure 5.26). Frit is an unglazed synthetic material, often used as a colourant or for small objects (Hatton *et al.* 2008: 1591). The main chemical components for frit are calcium, copper, and silica (Tite 1987: 27, Tite and Shortland 2008: 19). The structure of frit consists of partially reacted silica particles, and it was produced by efflorescence. The main difference between frit and faience is that faience has a distinctive layered structure, whereas frit has no structure, and the colour runs throughout the body (Moorey 1994: 167).

The speculation that these beads were made of frit was based on their appearance, because the colour was very matt and continued throughout the body, although there is a slight distinction at the surface (slightly darker), which could imply a glaze layer. The SEM images of these beads show partially reacted silica particles, and the composition of the beads is almost identical with the EDS standard for Wollastonite. However, upon further investigation it was determined that these beads were not frit, because their microstructure is unlike that of any frit in published reports, and the composition of the material is more mineral-like. At the moment all that can be said about these beads is that they are not faience, but

possibly Wollastonite mixed with copper to produce to the desired blue colour. The beads' production method is similar to that of faience beads.

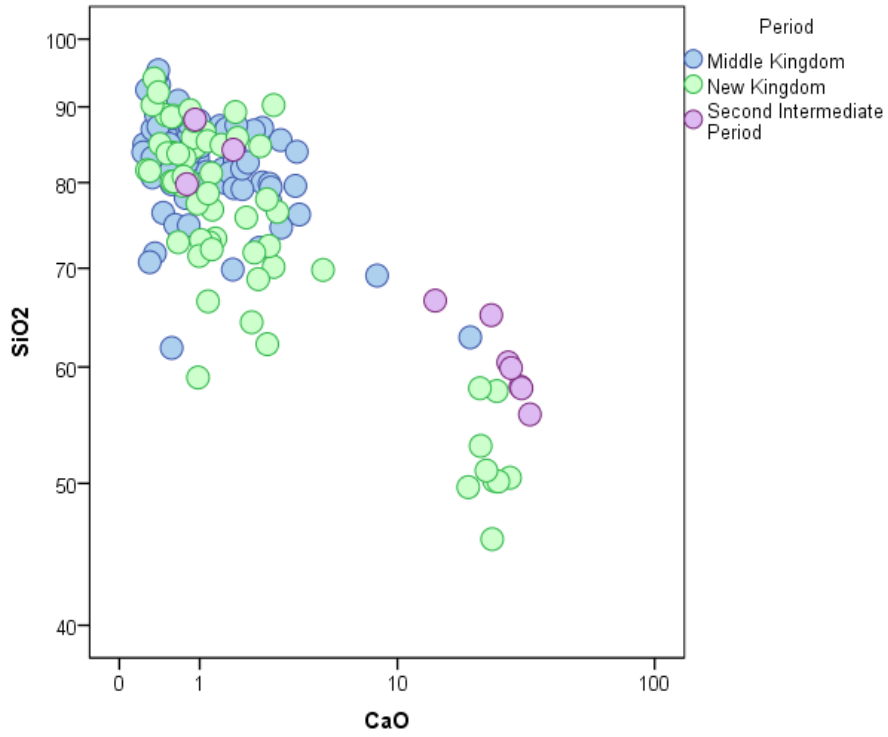


Figure 5.26: The silica percentage in comparison to the calcium percentage.

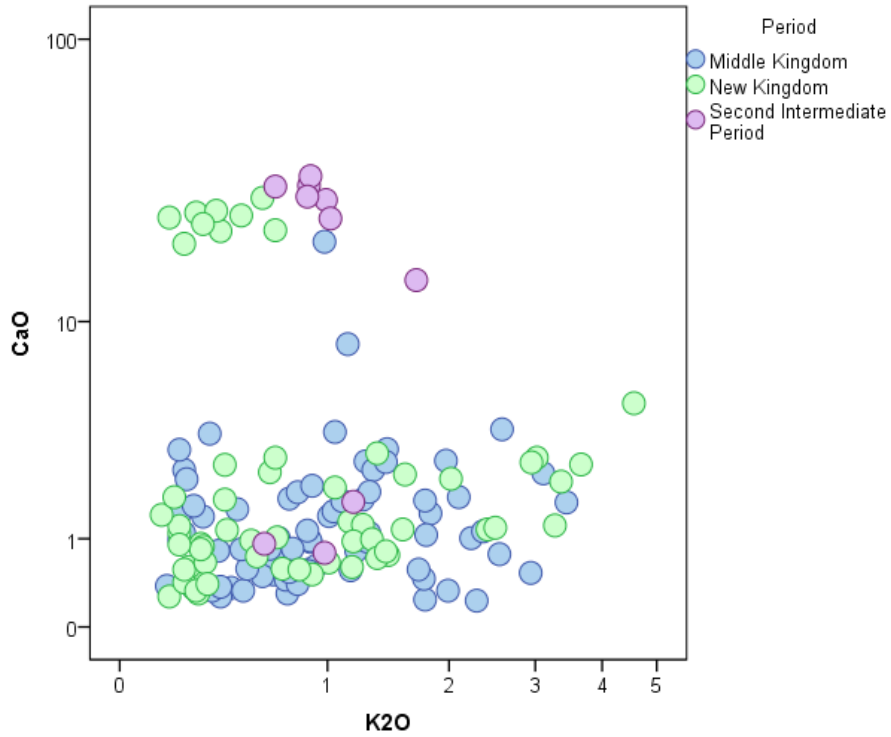


Figure 5.27: Calcium percentage plotted against potassium percentage to determine if the addition of lime was from the plant ash component.

5.4.3.3 ALKALI

There are three possible sources for the alkali in faience beads: natron, plant ash, and a combination of the two (mixed alkali). Both natron and plant ash are raw materials easily accessible within Egypt's own borders. The ashing of plants (terrestrial wood or maritime plant) was a common practice throughout Egypt and the Near East for both faience and glass production. Natron on the other hand has very few sources in antiquity one of which the Wadi Natrun in the Western Desert, which was easily reached from Abydos by a route from the mouth of the Wadi near the site (Redford 1992: 14, Tite *et al.* 2006: 1284).

The most common method used to determine the alkali source is based on the presence or absence of magnesium and potassium (Freestone *et al.* 2002: 257, Shortland and Tite 2000: 145, Tite and Shortland 2008: 38). Since natron (i.e. sodium) does not add anything to the composition of faience, beads made with this raw material source would lack magnesium, potassium, and lime (less than 0.5%) (Tite and Shortland 2008: 42). However, if the beads were made with plant ash as the alkali source, there would be an abundance of magnesium and potassium (i.e. potash) (Tite *et al.* 2002: 586). However, it should be stated that the level of magnesium might vary according to the type of plant used, and the part of the plant harvested (Henderson 1998: 77). Also, if the potassium quantities are equal to or greater than the soda quantities, then the faience bead was produced with a mixed alkali (Tite and Shortland 2008: 38). All of the compositional information was utilised to determine the alkali sources, the results of which are presented in Appendix H.

The samples for this research were predominantly produced with plant ash as the alkali source. This conclusion is based on the correlation of the sodium content with the potassium content, and the inclusion of magnesium, both of which are common indications of the presence of plant ash in faience compositions (Figure 5.28). Magnesium is present in the assemblage in a range of 0.63-21.37%, and potassium has a range of 0.42-4.56% (Figure 5.29). The Middle Kingdom beads seem to have a much wider range of magnesium than any of the other time periods. These ranges are quite widespread, but this could be due to the plants utilised for the production of these beads, and the spot analysis technique.

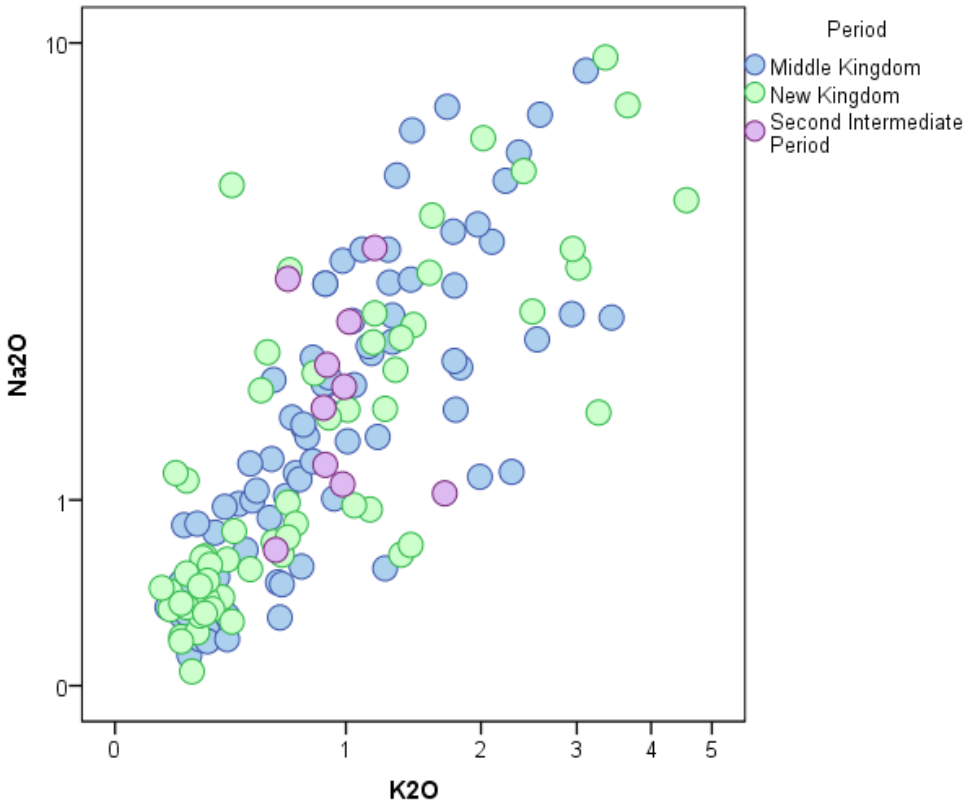


Figure 5.28: Sodium percentage correlated to potassium percentage in the faience bead samples.

For some of the beads, the magnesium and potassium contents were found to be at the lower end of the range for plant ash, and therefore suggest the use of natron for the alkali source. The low quantities of magnesium and potassium plus the high quantities of sodium indicate the use of natron (present in amounts of 0.83-9.42%). However, some of the beads with the higher quantity of natron consistently correlated with the high quantities of potassium, and indicate that either plant ash was in fact the alkali source, or a combination of alkali sources was utilised. Therefore, it can be said that in this assemblage all three alkalis could have been utilised in the production of these faience beads, although plant ash alkali is dominant. This will be further investigated in the next chapter to see if strontium isotopes hold the key to a better method for determining the alkali source.

Another element that was present in the assemblage of faience samples was chlorine. This element was present in a few beads from all time periods, and is likely to have been an impurity that was added with the alkali (Robinson *et al.* 2004: 91, Tanimoto and Rehren 2008: 2567). Both plant ash and natron can, however, produce high levels of chloride, so its presence does not aid in determining which raw material was used

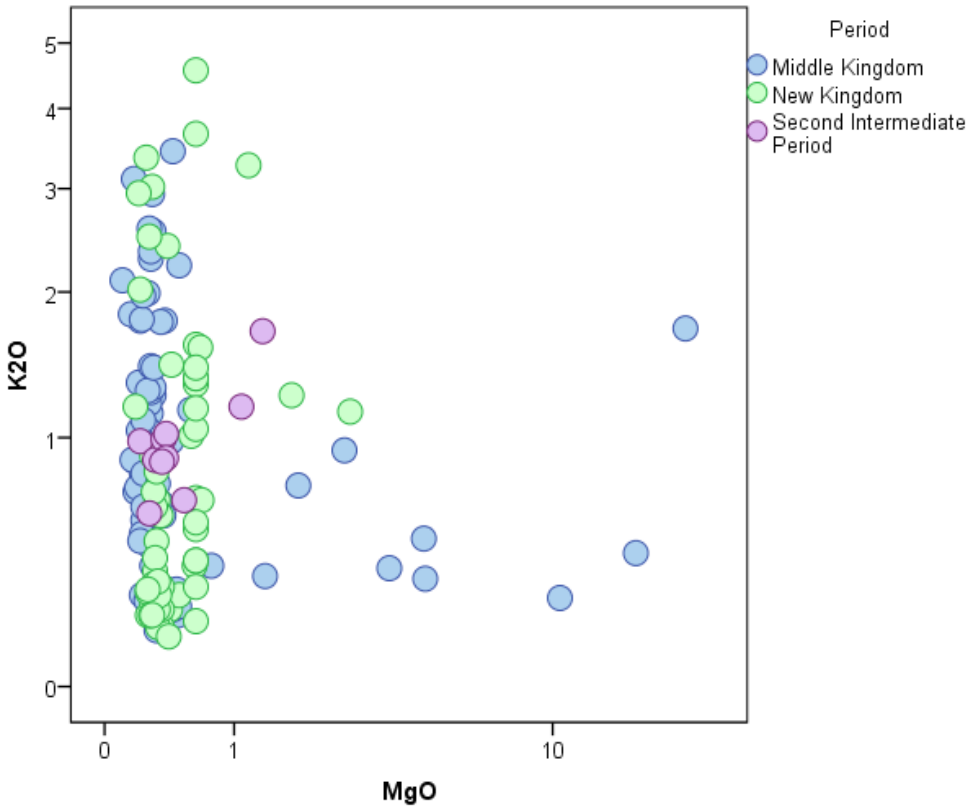


Figure 5.29: Comparison of potassium percentage to magnesium percentage, showing a distinctive grouping of all the periods with a wider spread of the Middle Kingdom beads.

5.4.3.4 COLOURANT

The remaining major component for the production of faience is the colourant. This is the element added to the raw materials, which produces the faience colour desired by the craftsmen. Colourants that are known to have been used include (but are not limited to) iron oxide and lead antimony for yellow, cobalt for dark blue or purple, manganese for purple or black, and copper for blue, green, and sometimes red (Noble 1969: 437). The method for determining the colourant utilised in the production of faience is based on the presence or absence of the elements mentioned above. If copper is present and the bead is blue, green, or red, then copper was the colourant used. However, if the bead is blue, and there is no copper present in the EDS results, then the bead was probably produced with cobalt (Kaczmarczyk and Hedges 1983: 61). In some cases, such as with New Kingdom bead 2384-6, if none of the above colourants are present and the bead is white, it is presumably so because the craftsman intended it to be and no colourants were utilised.

The vast majority of the beads analysed for this thesis were produced with the use of three colourants: copper, iron, and manganese. Copper and iron are the most abundant and are depicted in Figure 5.30, which shows the distribution of copper versus iron, based on bead colour. Several beads have both colourants present, but in vastly different quantities. The majority of red, reddish brown, brown, orange, and even some green beads have very high quantities of iron, but very low levels of copper. Other beads have very high quantities of copper, and the vast majority of these are either blue or green. Manganese is also present, sometimes with copper and iron, in several of the beads. The presence of manganese is noticeable as the faience is black or brownish black in colour.

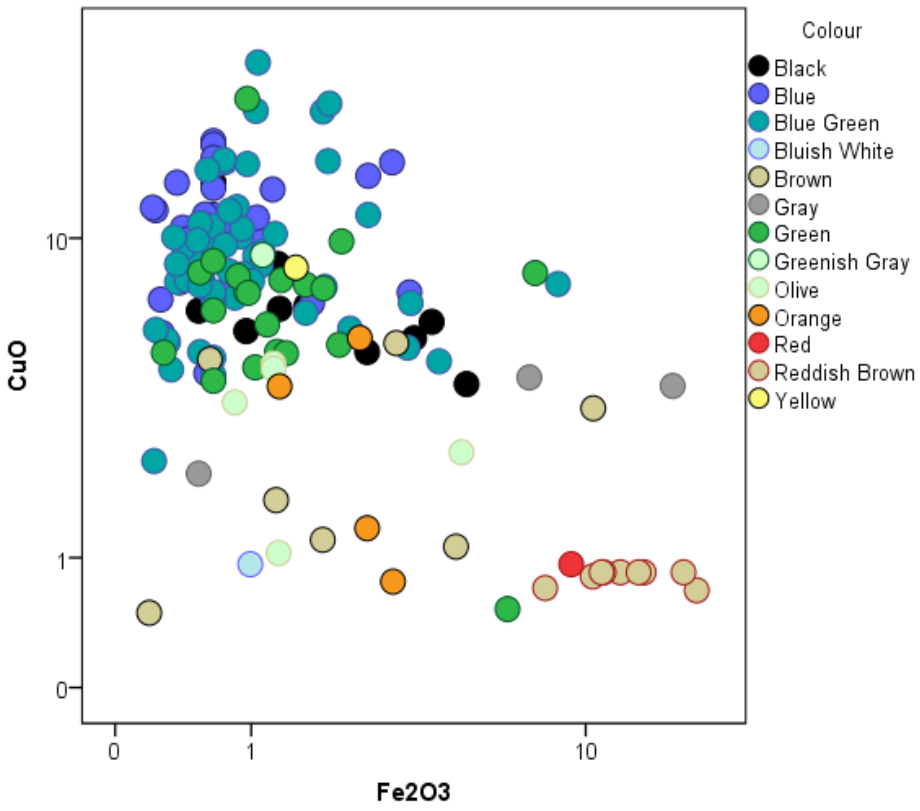


Figure 5.30: Copper percentage versus iron percentage based on the faience colours.

Copper is the dominant colourant used throughout the time span of Egyptian faience production. Copper is well suited to the production of faience because it migrates through the silica matrix of the bead, provided that one of the self-glazing methods is used. This is why it was possible and necessary to conduct the line and elemental mapping experiments mentioned earlier, in order to depict this migration. It is vital to understand the role copper plays, as it is considered to be the main

colourant used in beads found in Abydos (Tite *et al.* 2007: 1579). The quantity of copper found in the faience beads for this research ranges from 0.85% to 27.08%, the upper end of which can be considered quite high and is also a varied range.

There are several sources for copper in Egypt: the Eastern Desert and the Sinai Peninsula to name but two (Brad 1999). The copper utilised for the production of faience is usually considered to be from scrap metal, mineral, or even added to the faience material by copper drill bits utilised in the production of the silica raw material (discussed further in Chapter 7). The presence of several impurities can lead to the identification of the type of copper utilised. If the copper used was from scrap metal, then impurities from the scrap (such as tin) can be detected within the faience (MK Beads 2130-5, 2345-1, 2379-5 and New Kingdom 2344-1, 2344-2, 2380-1, 2380-3, 2384-1, 2384-3, 2384-4, 2384-6, 2384-7, 2384-8, 2389-1, 2389-2, 2389-3, 2389-5, 2389-6, 2389-10, 4075-1, 4075-4, and 4075-5). Tite *et al.* (2002: 586-587) have suggested that if there is an absence of tin, then the copper source could be a copper mineral, such as malachite.

The presence of zinc and sulphur has very little significance for faience but both are impurities from the copper utilised in its production. Zinc could aid in the identification of the copper source as the Eastern Desert, or it could be an impurity form the sand (Kaczmarczyk and Hedges 1983: 64). It is difficult to distinguish which of these two is the source of the zinc present in two of the beads (New Kingdom beads 2377-1 and 2377-2) because it is present in quite low quantities in comparison with the high copper levels. What is known is that it was neither added intentionally nor used as a colourant. Sulphur is present in quite a few more beads ranging from the Middle Kingdom to the New Kingdom (none in the Second Intermediate Period though). The sulphur is always correlated with high levels of copper and lower levels of iron, therefore the sulphur was probably associated with the copper rather than the iron, and was an impurity in the raw material sourced from a copper sulphide ore.

Egypt has abundant sources of iron as it comes from the sandstone and granite that forms the bedrock of Upper Egypt. Iron can be present as an impurity in the sand or plant ash, or intentionally added to produce a red, orange, or reddish brown colour (Robinson *et al.* 2004: 91, Kaczmarczyk and Hedges 1983: 35). The iron quantity ranges from 0.09% to 18.36% in the faience samples. The lower ranges would indicate that iron is present as an impurity, whereas the higher range would indicate its intentional addition as a colourant. The presence of iron as a colourant is observed in fourteen of the faience samples from all three time periods of interest.

Oddly enough, iron is present in another form altogether in several of the faience samples (32 in total from all time periods) as metallic prills (trapped metal droplets). These prills became apparent during the SEM-BSI process, as the iron has a higher atomic number than the other elements within the faience matrix (Figure 5.31, see also Appendix H). The presence of these metallic prills indicate that the beads were fired at a high temperature in a reducing atmosphere, as it is the only way such droplets could form. These prills will be discussed further in the Chapter 7 in the context of an experiment that attempted to replicate them.

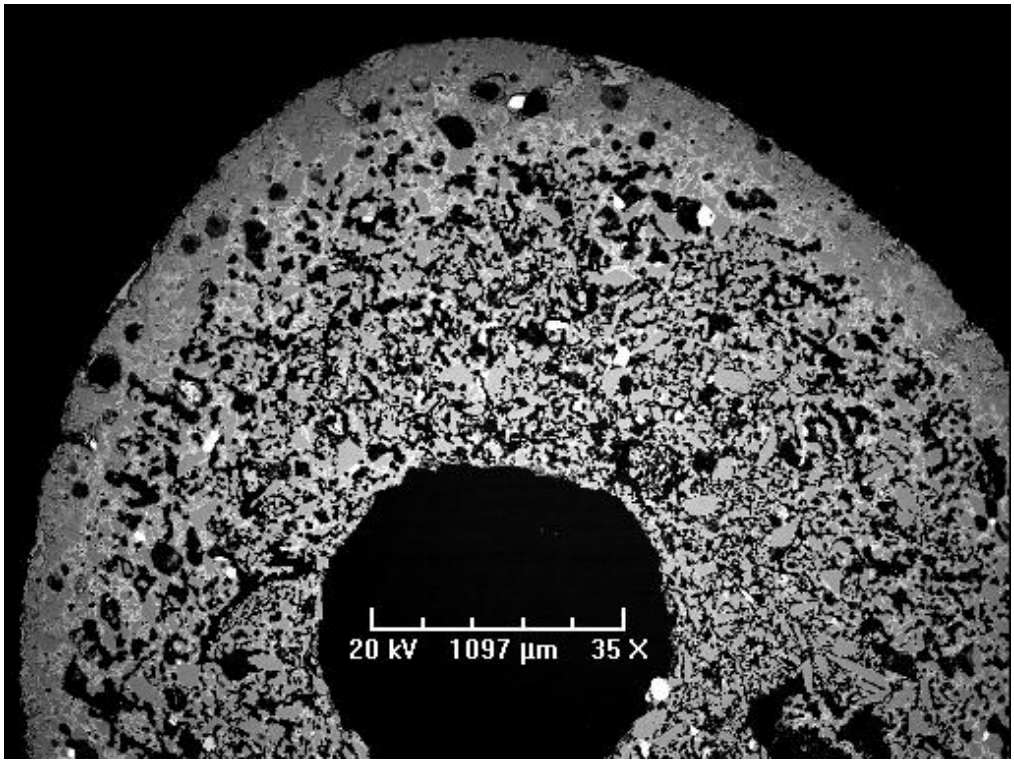


Figure 5.31: Iron prills (white droplets) within the faience bead structure (2377-2).

Another colourant present in this assemblage is manganese, which produces a blackish, brownish, or purplish colour in faience. Manganese was readily available in Egypt, with several deposits well used all over the country, as the mineral was used for cosmetic purposes among other things. It is a common impurity in sand and was sometimes added deliberately as a colourant or as a means to enhancing or darkening colours (Kaczmarczyk and Hedges 1983: 32). Manganese is present in the values of 0.69-18.64%, which suggests its presence in the assemblage is both as an impurity and as a colourant (depending on the bead). Fourteen beads in the assemblage derive their colour from manganese, since they are blackish brown and have very high levels of manganese (Figure 5.32). Other beads of a variety of colours including brown, greenish grey, and orange, also have high levels of

manganese, which correlates with iron when it is used as a colourant. One blue bead, which is more purplish blue in colour, also has high levels of manganese; this indicates that this is the colourant for this bead.

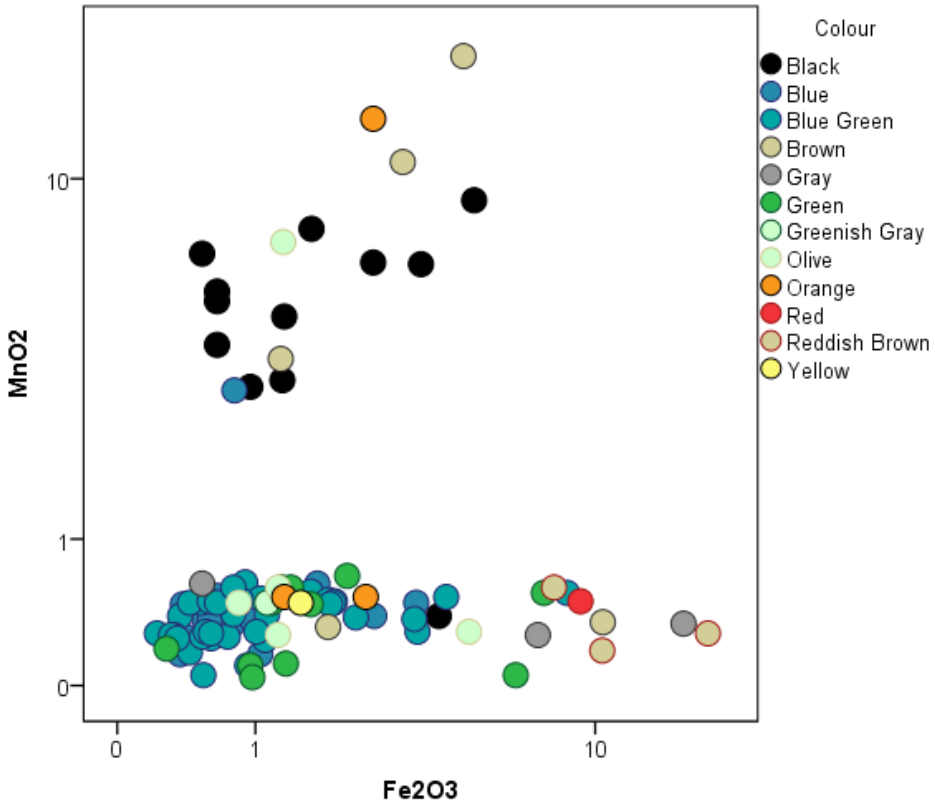


Figure 5.32: Manganese compared to iron based on colour, indicating that manganese is the colourant for the vast majority of the black beads.

The last colourant represented in this assemblage is lead antimony, with only one bead falling into this category (New Kingdom bead 2384-5), as it is both yellow and has high amounts of lead present, though antimony itself was undetected. Other beads in the assemblage contain lead, but in lower quantities and without any visible colourant effect. These beads are mostly from the New Kingdom assemblages (2380-10, 2384-2, and 2384-3). Corresponding with iron the antimony is present in two New Kingdom beads 2384-2 and 2384-3.

There is also one Middle Kingdom bead that contains lead: 2383-5. This should not be the case, as lead was not introduced into faience technology until the New Kingdom. This is therefore either the earliest known lead-glazed faience bead, or its provenance is incorrect, or the lead is a natural impurity (Stone and Thomas 1956). Further research needs to be undertaken to determine its origins, as there is the possibility that this bead was produced outside Egypt. However, Kaczmarczyk

and Hedges (1983: 110) suggest that lead can be found throughout all the faience-producing time periods in Egypt, albeit sporadically, due to the sources for the material being so close. There are two possible sources for lead; and they are in the form of the pure natural metal itself or galena, which can be obtained from mountains near the Red Sea (Kaczmarczyk and Hedges 1983: 110, Shortland 2000: 51). Lead can also appear as an impurity in copper, and since all of the beads (apart from 2384-5) are blue and have an abundance of copper as the colourant, the lead is here assumed to be either an impurity or an enhancer for the glaze in the New Kingdom beads.

5.5 Conclusions

There have been many general statements made about faience technology in Egypt, and how the technology changed from one period to the next (see Chapter 1 and 2 above). These statements will be discussed next, and then all of the results from the SEM-EDS analysis will be compared, so that conclusions may be drawn concerning the ways in which faience technology changed from one period to the next. These interpretations will be based on the chemical composition results from the EDS system and the interstitial glass levels apparent in the SEM-BSI images of each sample.

5.5.1 Middle Kingdom Results

The faience made in this time period, according to previous publications, is usually produced with sand as the silica source, plant ash as the alkali, copper as the colourant in a range of 0.5-5%, and utilising all three glazing methods (Shortland *et al.* 2006: 522). The results obtained from the analysis of the sample assemblage hold true to these generalisations except for the quantities of copper, the addition of other colourants, the types of glazing methods used, and the possibility of other alkalis being used.

The copper quantities in the faience beads analysed for this research far exceeded the concentrations mentioned above (from the limit of detection <0.85 to 27.08%). This could be due to the method of spot analysis used, which aims for the interparticle glass, which would be higher in copper. Alternatively, the higher quantities could be due to the vast majority of past research being conducted as bulk analyses, in which the larger quantities of silica would overshadow the smaller amount of copper by a calculated percentage.

Copper is not the only colourant present in the Middle Kingdom. Iron and manganese are also present as colourants. Out of 81 beads, four beads were

produced using iron as the colourant, and eight beads were produced with manganese. However, the vast majority of the beads were produced with copper as the colourant, which was the expected result. This assemblage just shows that there is a little more variability than suggested or expected, on the basis of previous publications on this topic.

Another difference between this assemblage and that of previous works is that there was only one case of application glaze, which was used for a stone bead (bead 9384-10). The majority of the other beads from this period were glazed by efflorescence (53 beads out of 81 of the assemblage) and only twenty beads were glazed by cementation. The remaining seven beads fall into the category of unknown material type, and were likely glazed by the cementation method. These beads were originally thought to be frit, however they are now classified as mineral-based, because of their dissimilarity to the descriptions presented in published studies of frit. These beads compositionally match the Wollastonite standard used for the EDS calibration; therefore they will be referred to as Wollastonite beads for lack of a better description.

The final difference between this assemblage and the published research on faience is that there is more variability in the alkali sources. There are eleven beads, which possibly have natron as their alkali source, and there are also two beads that could incorporate a mixed alkali. These conclusions led to several questions about the best way to determine which alkali was utilised. The quantities can be so low, and with the possibility of sodium burn-off, another analytical method (strontium isotope analysis) was used to determine the alkali. This method will be presented in Chapter 6.

5.5.2 Second Intermediate Period Results

Not much has been written about Second Intermediate Period beads other than that they are similar to the Middle Kingdom beads in their production methods. In this assemblage there are two distinct bead groups: the ‘normal’ and the ‘unknown’ or Wollastonite beads. Those of the ‘normal’ faience variety are very similar to Middle Kingdom beads. The three beads that fall into this group are produced with sand as the silica source, and plant ash as the alkali and copper as the colourant. Two of the beads are glazed with efflorescence and one with cementation. The remaining seven beads fall within the ‘unknown’ type; these are the beads mentioned earlier, which were initially thought to be frit but are now simply classified as unknown material or possibly Wollastonite beads. These beads were likely cementation glazed. These beads were also subjected to strontium isotope

analysis to better understand their production methods, and the results will be presented in Chapter 6.

5.5.3 New Kingdom Results

New Kingdom faience seems to have been studied a lot more frequently than faience from other time periods, judging from sheer number of publications alone. This is probably because the introduction of glass technology happened during this time, and this was thought to have produced changes in the ways in which faience was made. These changes include the introduction of cobalt as a colourant for blue and purple faience, and the introduction of other colourants. It has also been suggested that (1) the average New Kingdom faience bead would have been produced with sand or quartz pebbles, (2) the alkali sources would more likely have been natron than plant ash, especially if cobalt was used as the colourant, and (3) the glazing methods would have been efflorescence or application, with a drop in the use of cementation-glazing (Shortland and Tite 2000: 141).

The New Kingdom faience beads from this sample assemblage seem to have been made in the same way as the Middle Kingdom beads. The silica source was sand, the alkali was mostly plant ash, with a few exceptions (six possible natron beads, and four possible mixed alkali beads), and the colourant was usually copper. There is no cobalt present in any of the beads. Cobalt would be determined on the basis of a lack of copper and the beads being blue, but all beads have a component of copper and, if not, their colourant is either manganese (five beads) or iron (seven beads). However, there are two beads that are different: one is coloured with lead (possibly with antimony) and is yellow in colour, the other has no obvious colourant, although it is white, and the absence of colourant was presumably intentional.

As for glazing methods, 45 out of 60 New Kingdom beads were glazed by efflorescence and five were glazed by cementation. This verifies the expected drop in the use of cementation glazing during this time period. It should be noted that the remaining ten beads fall into the category mentioned above as the unknown or Wollastonite types and were possibly glazed by cementation. For the most part, the New Kingdom beads in this assemblage lack the variability that was expected on the basis of past research.

5.5.4 Comparison of Results

The Middle Kingdom, Second Intermediate Period, and New Kingdom beads were more similar in their production methods and chemical composition than originally thought. The primary production methods of the three assemblages

comprised (1) sand as the silica source, (2) plant ash as the alkali, and (3) copper as the colourant, with a few variables by time period mentioned above (Appendix H). The glazing methods were usually efflorescence, with some cases of cementation, and one application glazed stone bead. The expected variations and differences between time periods are not pronounced in this sample assemblage, and the characterisations of the time periods do not apply. Therefore, these generalisations should be modified and possibly discarded altogether.

The approach to faience should be modified and, instead of searching for variability in time periods, a search for variability in material type might be better suited for observing the technological changes. The technology might have varied depending on what type of object was being made. Since all of these faience samples were beads, the possibility is that all faience beads were produced in very similar ways throughout the history of the material. If one were to inspect other artefacts, such as vessels or rings, they might lack variability in the assemblages too. The Egyptians might have modified faience technology to suit the artefact they were producing, and even though the introduction of glass technology changed some of the production methods, they might not necessarily have been incorporated into the standard bead production strategies. This will be discussed further in Chapter 8.

Chapter 6: Strontium Isotope Analysis

6.1 Introduction

There have been recent advances in the study of ancient glass through the application of strontium ($^{87}Sr/^{86}Sr$) isotope analysis. This method of analysis is used to determine the geological sources of the raw materials used in the production of glass, i.e. the alkali and lime sources, and the possible location of the production sites/raw materials (Freestone 2005: 008.1.1, Foster and Jackson 2009). Potentially the same results could be obtained for faience, as it has the same soda-lime-silica composition as ancient glass from the same period. Therefore, this study has been undertaken to recreate the success of strontium isotope analysis on faience, and is the first to do so, with the possible exception of Boschetti *et al.* (2008) who conducted work on faience from Italy, the results of which remain unpublished at the submission of this thesis.

There are four objectives and aims for this research: the first of which is to determine if there is enough strontium in faience for this analysis to be successful, in case diagenetic alteration has affected the strontium levels in the faience beads. This would be caused by the less stable nature/structure of faience in comparison with glass's harder crystalline structure, which would affect the analysis to the point where primary strontium values would not be observed. It should be noted here that these beads are from tombs and may never have been truly buried (surrounded by soil). Hence re-equilibration with the soil (diagenesis) might be ruled out. Secondly, the use of strontium isotope analysis to study the possible alkali raw material sources used in the production of faience will be addressed by analysing the concentration levels of strontium in the faience bead samples. Thirdly, to determine the viability of the use of strontium isotope ratios to indicate the possible origin of the faience/raw materials is assessed. Finally, the overall objective of this analysis is to discover if there is isotopic variation in faience from the Middle Kingdom and that from the New Kingdom and, if so, this approach will become part of a developing methodology for determining the raw material sources utilised in faience production.

This chapter will first present the background to the geological research, and the different types of isotopic analysis that have been completed on ancient glass. Then the results of a pilot study undertaken with the help of the Natural Environmental Research Council Isotope Geosciences Laboratory (NIGL) in Nottingham (Grant Ref. IP11451109) will be presented. The pilot study presents

strontium concentrations and isotope analysis on 26 samples taken from the larger sample set studied for this PhD research.

6.2 Background

In order to understand the isotopic research that has been carried out in the Mediterranean and Egypt on glass and faience, one must begin with the previous research provided by geologists on the basic geology of the area. Geologists have used isotopes to study chemical stratigraphy, geochronology, provenance, and studies of temporal changes in earth surface processes, for several decades (Banner 2004: 141, Stanley *et al.* 2003). Now, due to the increase in interdisciplinary research, archaeologists are beginning to use isotopes to study artefacts in much the same way, by analysing the raw materials utilised in their production.

Isotopes are different forms of the same chemical element with identical chemical properties. They have the same number of protons but different numbers of neutrons in their nucleus, hence each form has a different atomic mass. The element strontium has four naturally occurring isotopes ^{87}Sr, ^{84}Sr, ^{86}Sr, and ^{88}Sr. Three of the isotopes (84, 86, and 88) are referred to as "stable", indicating that their mass does not change by elemental decay, but ^{87}Sr is derived by radioactive (beta particle) decday from Rubidium (^{87}Rb). The ^{87}Sr accumulates in proportion to the amount of Rb, and the passage of time (Banner 2004: 143). Strontium is associated with calcium. One of the three major components of faience is calcium; therefore, in theory, strontium should be present.

The $^{87}Sr/^{86}Sr$ ratio is one of several isotope signatures used by geologists to trace the origins of rocks and minerals and, in more recent years, this technique has been adopted by archaeologists to look at, among other things, the source of raw materials used in glass making (Degryse *et al.* 2006: 496). The strontium tracks calcium through the glass making process, and can be incorporated into glass in a number of ways: 1) with the lime/seashells added deliberately or as part of the sand component, or 2) via the plant ash, when this is a source of alkali. The strontium composition of limestone has fluctuated through time, as it represents the Sr isotope composition of seawater at the time of its formation (Burke *et al.* 1982: 519).

Strontium isotopes in seawater vary with time, climate, and changing continental positions (Mcarthur *et al.* 2001, and for application to archaeology and glass making, see Tite and Shortland 2008: 215). The strontium is absorbed into marine carbonates such as shell and limestone, which reflect the composition of the seawater at the time that they were formed (Freestone *et al.* 2003, Tite and Shortland 2008: 215). Modern ocean water and modern shells have a $^{87}Sr/^{86}Sr$ ratio

of approximately 0.7092 (Freestone 2005), which reflects the high $^{87}Sr/^{86}Sr$ ratio of modern seawater in comparison with geologically earlier times (Burke *et al.* 1982: 519).

The plants used for plant ash alkali almost certainly grew on Nile sediments. Freestone *et al.* (2009 a) mapped the strontium concentration and ratios in Nile River sediments and this data provides the baseline for plant ash alkali component. Due to work by Krom *et al.* (2002), it is possible to map the changes in strontium ratio in the Nile River, over the course of time, by studying the depth profile of $^{87}Sr/^{86}Sr$. Thus Krom *et al.* (2002: 72) were able to map out the peaks of strontium ratios over time, showing that the highest values (0.7088) were older than 6000 years, and that the levels then decreased to a minimum of 0.7078 around 4670 years BP, before fluctuating between 0.7080 and 0.7082 to the present. During these years of fluctuation fall the relevant time periods of interest, the Middle Kingdom (c.2040–1640 BC) and the New Kingdom (c.1570–1070 BC). This study provides a foundation for strontium isotope studies related to the Nile, since they supply geological information and dates for fluctuations in strontium over time.

6.2.1 Glass Strontium Isotope Analysis

Strontium isotopes have proven to be useful in distinguishing between the two alkali types used for glass: natron and plant ash (Leslie *et al.* 2006, Freestone 2005). Natron itself does not add very much in the way of lime to the glass; the level of strontium is usually reflective of the geological environment of the lime source, whether it be shell or limestone, and is not affected by the alkali (Leslie *et al.* 2006, Freestone 2006, Degryse *et al.* 2009 a: 18). Therefore, natron glass has a very small range in its strontium ratios, between 0.7088 and 0.7092 (Henderson *et al.* 2005: 672).

Plant-ash glasses have a much more diverse set of raw materials, which can vary according to which part of the plant was harvested, or which species of plant, or even according to the environment in which the plant grew (Henderson 2009: 136). Plant ash contributes significantly to the strontium concentrations of the glass and has a wider range of strontium ratios (0.7079 to 0.7084) than natron but they do not overlap (Freestone *et al.* 2009: 34-35, Henderson *et al.* 2005: 672). Strontium isotope analysis has the potential to overcome the complications of all the variables mentioned above, since plants (no matter what the species) will obtain the same isotopic signatures as the dominant bedrock of the same age in the area where they grew (Henderson 2009: 137). Since plant ash contains both alkali and lime, isotopic analysis is essential to determine which raw materials were used (Freestone 2006:

205). However, it should be noted that although strontium might be able to indicate the mineralogy of the added lime, it cannot determine whether or not it was added deliberately (Freestone 2006: 207).

Strontium isotope analysis can also aid in determining which lime source was used in the production of glass, as shown by Wedepohl and Baumann (2000) who concluded that, in the case of Roman glass, the higher the strontium ratios, the more likely that marine biogenic carbonate (shell) was used, and conversely the lower the ratios, the more likely that limestone was added. This is due to the fact that marine molluscs obtain their Sr from seawater, which has increased its $^{87}Sr/^{86}Sr$ ratio from 0.7068 in the Jurassic to 0.70918 at present (Wedepohl and Baumann 2000: 130). Limestone has a lower level of strontium due to diagenesis (a chemical or physical change in the limestone after its initial deposition and lithification) (Freestone *et al.* 2009 a). This happens over time as the limestone slowly equilibrates with the ground water, which then lowers its strontium concentration.

6.3 Methodology

6.3.1 Sample Selection

The faience samples were selected from a cross-section of the time periods of interest, colour types, chemistry, and their suitability for destructive analysis (Table 6.1). Out of 151 beads, 26 were selected for strontium isotope analysis (nine Middle Kingdom beads, seven Second Intermediate Period beads, and ten New Kingdom beads). As permission for destructive analysis was only granted by the Garstang Museum, all of the beads in this study are from this collection.

As part of the sampling strategy, the Middle Kingdom and Second Intermediate Period beads with the largest quantities of calcium were selected for this analysis, based on the known correlation of strontium and calcium. This was determined by SEM-EDS (see Chapter 5). However, this method was not applied to the New Kingdom beads because they had not yet been analysed by SEM-EDS. Instead they were selected to represent the variability in the assemblage and based on colour and other stylistic variations.

PERIOD	SAMPLE NUMBER	TOMB	COLOUR	CALCIUM %
MK	E2379-10 glaze	359 A'07	Blue/Green	0.40
MK	E2379-10 core	359 A'07	Blue/Green	0.27
MK	E2345-2	330 A'07	Red	080
MK	E2345-4	330 A'07	Red	1.5
MK	E2383-6	498 A'08	Green	19.60
MK	E2345-3	330 A'07	Red	1.58
MK	E9384-2	9 A'06	Black	2.97
MK	E9384-6	9 A'06	Black	1.1
MK	E2130-4	427 A'07	Blue/Green	1.95
SIP	E2385-1	458 A'08	Deep blue	0.72
SIP	E2385-4	458 A'08	Deep blue	30.75
SIP	E2385-5	458 A'08	Deep blue	31.04
SIP	E2385-6	458 A'08	Deep blue	14.22
SIP	E2385-7	458 A'08	Green	27.55
SIP	E2385-9	458 A'08	Yellow Green	33.46
SIP	E2385-10	458 A'08	Yellow Green	28.33
NK	E2380-5	492 A'08	Blue	1.18
NK	E2344-1	942 A'09	Blue glaze and core	2.71
NK	E2389-2	649 A'08	Red glaze and core	0.94
NK	E2384-4	525 A'08	Orange	2.31
NK	E2384-5	525 A'08	Yellow glaze and core	0.90
NK	E2384-6	525 A'08	White glaze and core	2.57
NK	E2375-6	577 A'08	Blue/Green	0.98
NK	E2375-8	577 A'08	Blue/Green	0.81
NK	E2389-7	649 A'08	Light Green	0.13
NK	E2377-2	541 A'08	Pale Green	0.99

Table 6.1: Selections are representative of the variability in the whole collection of the periods in question. The time periods have been abbreviated Middle Kingdom (MK), Second Intermediate Period (SIP), and New Kingdom (NK).

6.3.2 Sample Preparation

Half of each bead was available for destructive analysis; the other half having been resin mounted for SEM-EDS analysis (see Chapter 5). The approach to this analysis, since isotope analysis of faience has not been published before, was to treat the samples in the same manner as archaeological glass samples. The samples were first cleaned to remove any surface contamination, by placing them in

dilute (~2 moler hydrochloric acid (M HCl) after which the samples were rinsed three times with deionised water, and placed into beakers on a hot plate set to 80^{o} C to dry. Once dried, they were reduced to a fine powder using an agate pestle and mortar. These were cleaned with methanol between samples to avoid cross contamination. Ball bead E2379-10, which was one of the larger samples, was separated into two pieces, the glaze and the core, in order to determine if there was any variation between the two layers. This would indicate if the bead was subject to weathering, as the exterior would have a different strontium reading than the interior.

The resulting powders were then transferred to a clean (class 100, laminar flow) working laboratory, weighed into clean Teflon beakers, and a known amount (30µl) of ^{84}Sr enriched tracer/spike solution was added to each sample, in order to obtain Sr concentrations as well as the isotope ratio. The samples were dissolved in a combination of 8 moler hydrochloric and nitric acid (M HNO3) and 24 moler hydrofluoric acid (M HF), and left overnight on the hot plate at 80^{o} C. The samples were then converted into chloride form using Qz distilled 6 M HCl, dried down and then taken up in 2.5 M HCl ready for column chemistry. The strontium was separated using The Dowex resin columns system (Dickin 1995).

6.3.3. Mass Spectrometry

Strontium was loaded onto a single Re Filament with Tantalum Fluoride (TaF) following the method of Birck (1986) and the isotope composition and concentrations were determined by thermal ionisation mass spectroscopy (TIMS) using a Thermo Triton multi-collector mass spectrometer. The strontium isotope data are normalised to the internationally accepted value of ^{86}Sr/^{88}Sr =0.1194. The international standard for ^{87}Sr/^{86}Sr, NBS987, gave a value of 0.710251 ± .000005 (n=19, 2σ) during the analysis of these samples. Recent analyses of BCR-2 international standard give 0.705036 ± 0.000038 (1s, n=4) for external reproducibility of a silicate powder. Blank values were in the region of 100pg. Sr concentrations are accurate to ~± 10%.

6.3.4 Data Assessment

The best precision on concentration is achieved when the amount of strontium in spike and samples are similar. This depends upon knowing/predicting approximately how much strontium is in the sample. Once the results were produced, it was clear that there was a much wider range in Sr concentration in the faience samples than could have been predicted from experience based on glass analysis. This meant that some of the samples were over- or under- spiked; a

situation that can lead to error magnification (Dickin 1995) which could influence the isotope ratios. To assess the possibility that this may have introduced errors or bias into the data, two of the samples with the lowest Sr ppm (E2379-10 core and E9384) were re-analysed with the appropriate amount of spike. The $^{87}Sr/^{86}Sr$ isotope ratios ± 0.00002 (E2379-10 core) and ± 0.00004 (E9384) are within, or close, to the reproducibility given above for BCR-2, and therefore provide no evidence for any error introduced during spiking (Table 6.2).

SAMPLE	SR PPM	$^{87}SR/^{86}SR$
E2379-10 core	14	0.707877
E2379-10 core	17	0.707859
E9384-2	32	0.708557
E9384-2	56	0.708515

Table 6.2: Bead 2379-10 and 9384-2 re-analysed to check for errors.

6.4 Results

The strontium analysis results are presented in Table 6.3 and will be discussed first by Sr concentration compared to Sr ratios ($^{87}Sr/^{86}Sr$) in order to summarise the data obtained. Then a comparison of the data with published results of strontium isotope analysis on ancient glass will be introduced, in order to better understand the results. The last section will then present the strontium results by time period, to determine if there was any variation from one to the next.

6.4.1 Faience Strontium Isotope Analysis

The strontium isotope results for faience are very promising. The faience samples record a very wide range in values in both its strontium concentrations and ratios (Figure 6.1). The concentrations vary from 17,478 ppm to only 12 ppm. The very high levels could be indicative of very well ashed plants as the source of both the strontium and calcium. The very low levels are representative of natron as the alkali source, which would contribute neither calcium nor strontium to the beads' composition. Also the range in the strontium ratios is quite wide for the faience samples, 0.7075-0.7085, however this is consistent with limestone.

These wide ranges of strontium compositions and concentrations lend support to the argument that these results reflect the primary composition of the samples, and do not reflect diagenetic alteration. The Middle Kingdom bead 2379-10, which was sampled in layers, also supports this. Both the core and glaze sample

provide the same results (see Figure 6.1) and therefore discredit any possible diagenetic alteration, successfully achieving the first aim of this research.

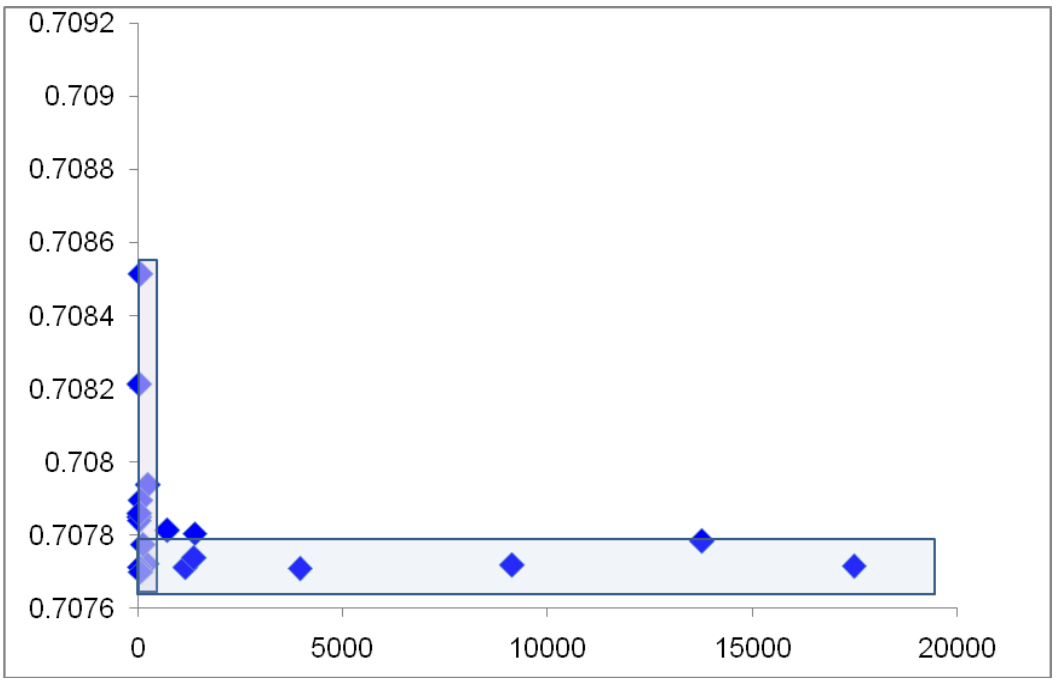


Figure 6.1: Strontium ratios ($^{87}Sr/^{86}Sr$) compared to strontium concentration (ppm).

6.4.2 Comparison of Faience to Glass Sr Isotope Analysis

The faience strontium isotope results are compared with the results of previous publications on ancient glass isotope analysis in order to provide a context for the faience results (see Appendix I for the raw data) (Freestone 2003, Henderson *et al*. 2005, Leslie *et al.* 2006, Degryse and Schneider 2008, Degryse *et al.* 2010 a, Degryse *et al.* 2010 b, Henderson *et al.* 2010). This comparison with a compositionally similar material was undertaken to better evaluate the faience results, and to develop a wider context for the interpretation of faience strontium results in general. The first observation made when undertaking this comparison, is that faience has a much wider range of strontium than glass, as compared with natron, plant ash, and glass of undefined alkali source (due to the lack of identification by the publication (Freestone 2003, Degryse *et al.* 2010 a, Degryse *et al.* 2010 b, Henderson *et al.* 2010), which are all more consistent (Figure 6.2).

SAMPLE #	PERIOD	WEIGHT (G)	84 Sr SPIKE (µl)	Sr PPM	87Sr/86Sr RATIO	COLOUR	CALCIUM %	GLAZE
E2379-10 Glaze	MK	0.1102	30	17	0.70784	Blue/green	0.40	Cementation
E9384-2	MK	0.8620	30	56	0.70851	Black	2.97	Cementation
E2383-6	MK	0.0140	30	1346	0.70773	Green	19.60	Cementation
E2345-3	MK	0.0020	30	48	0.70789	Red	1.58	Efflorescence
E2345-4	MK	0.0012	30	1374	0.70780	Red	1.58	Cementation
E2130-4	MK	0.0110	30	107	0.70777	Blue/green	1.95	Cementation
E2379-10 Core	MK	0.1153	30	17.21	0.70785	Blue/green	0.27	Cementation
E9384-6	MK	NA	30	494	0.70786	Black	1.1	Efflorescence
E2345-2	MK	NA	30	21	0.70855	Red	0.8	Efflorescence
E2344-1	NK	0.0566	30	1160	0.70771	Blue G/C	2.71	Cementation
E2389-7	NK	0.0053	30	230	0.70793	Light Green	0.13	Cementation
E2389-2	NK	0.0410	30	717	0.70781	Red G/C	0.94	Cementation
E2384-6	NK	0.0019	30	213	0.70772	White G/C	2.57	Efflorescence
E2384-5	NK	0.0051	30	12	0.70783	Yellow G/C	0.90	Cementation
E2375-8	NK	0.0026	30	14	0.70771	Blue/green	0.81	Cementation
E2377-2	NK	0.0481	30	31	0.70821	Pale green	0.99	Cementation
E2384-4	NK	NA	30	293	0.70791	Orange	2.31	Cementation
E2380-5	NK	NA	30	4429	0.70776	Blue	1.18	Efflorescence
E2375-6	NK	NA	30	128	0.70805	Blue/green	0.98	Efflorescence
E2385-9	SIP	0.0006	30	17478	0.70771	Yellow/green	33.46	Cementation
E2385-5	SIP	0.0004	30	13763	0.70778	Green	31.04	Cementation
E2385-4	SIP	0.0018	30	3940	0.70770	Green	30.75	Cementation
E2385-6	SIP	0.0008	30	9135	0.70771	Green	14.22	Cementation
E2385-1	SIP	0.1048	30	59	0.70770	Blue	0.723	Cementation
E2385-7	SIP	NA	30	872	0.707743	Green	27.55	Cementation
E2385-10	SIP	NA	30	889	0.707746	Yellow/green	28.33	Cementation

Table 6.3: Strontium isotope results for faience beds.

In this study, strontium is being targeted to see if it can help to identify the alkali sources of faience material. Samples such as E2384-5 have very low concentration levels (12 ppm), which are indicative of limestone as the calcium source. Therefore, natron would have been the alkali source. In other cases, the Sr concentration is high. E2380-5 has 4429 ppm, which is higher than most glass samples, and is indicative of plant ash as the alkali source. In viewing Figure 6.2, there are two distinct groupings of known natron and plant ash glass groupings. The faience samples are well mixed among the plant ash glass range, with natron glass positioned above. The ratios for the faience data are within the plant ash ratios, but have a wider range of concentrations. The results from these beads indicate that they are almost all produced with plant ash as the alkali source. However, there are a few that hint at natron as a possible source, which will be clarified in Section 6.5.2.

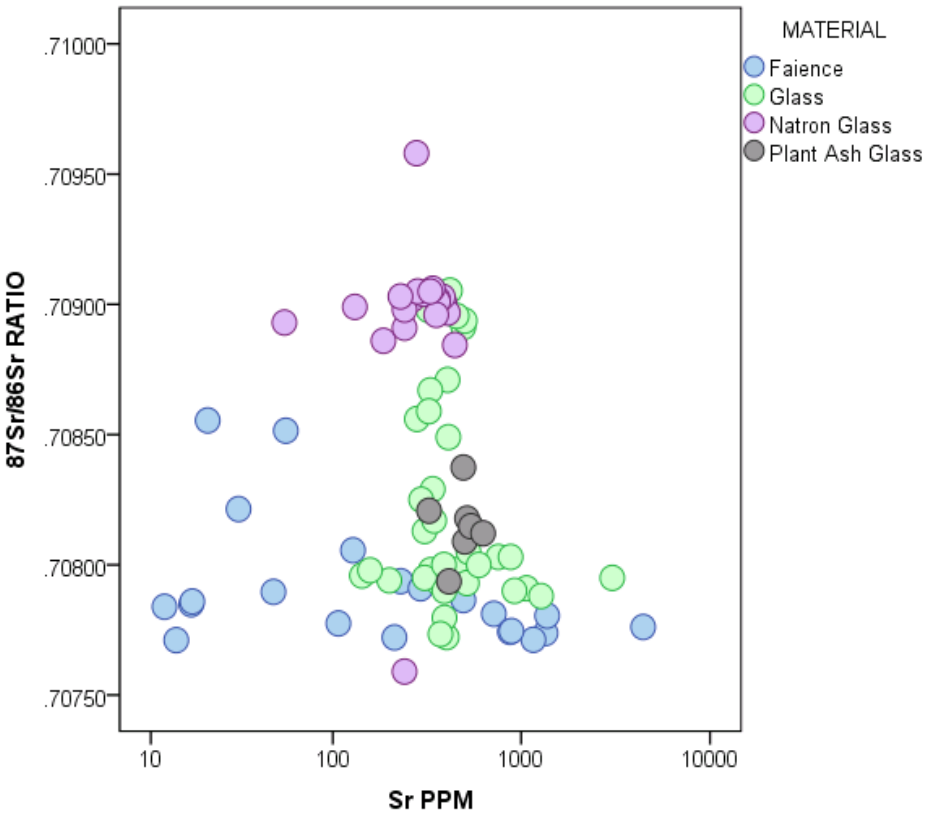


Figure 6.2: Sr ratio ($^{87}Sr/^{86}Sr$) versus concentration (ppm) based on material type from published research (Freestone 2003, Henderson *et al*. 2005, Leslie *et al.* 2006, Degryse and Schneider 2008, Degryse *et al.* 2010 a, Degryse *et al.* 2010 b, Henderson *et al.* 2010). The category of glass can either be natron or plant ash glass, the distinction between the two was not always made by the published research from which this data was obtained.

When the strontium concentration results of the faience samples are compared to glass from archaeological sites, the majority of the Egyptian faience samples fall outside the expected ranges of ppm for ancient glasses, most of which are from the Near East (Figure 6.3: for each box, the top and bottom horizontal line represents the highest and lowest quantities with the middle line representing the median. The two vertical lines graphically represent the full range of the data, the central bunch of the data batch (Drennan 2004: 37)). When a closer inspection is taken of the Egyptian sites only, the faience seems to match more closely with the glass, although it is still slightly lower (Figure 6.4).

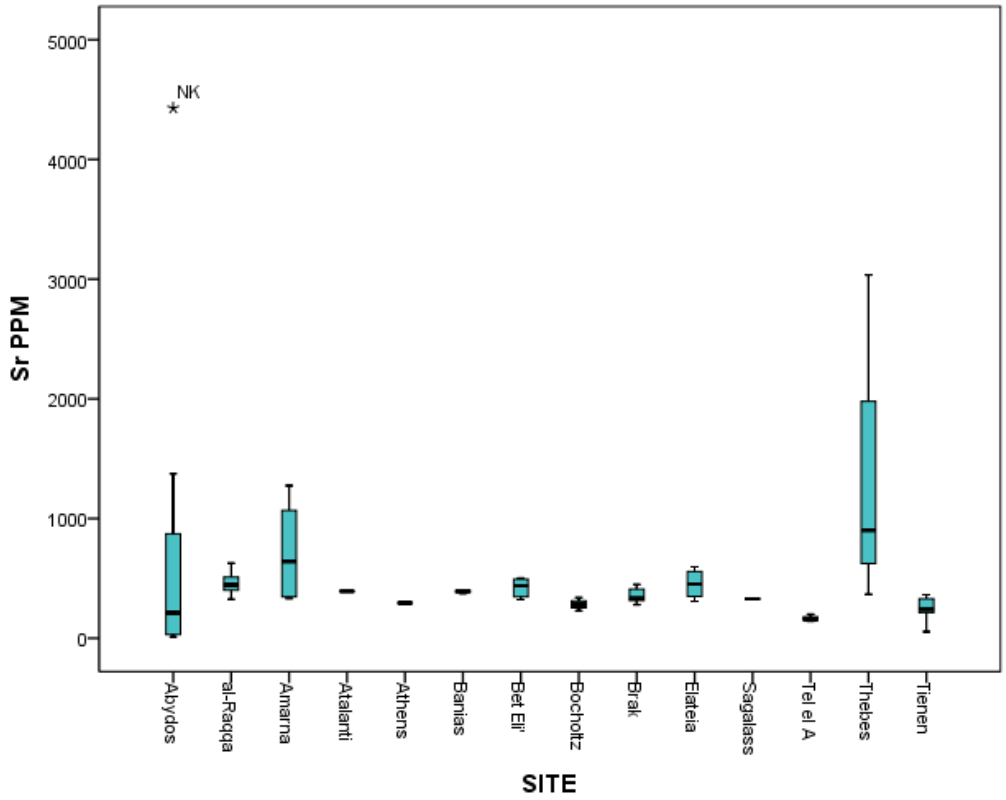


Figure 6.3: Sr concentrations (ppm) of Abydos faience compared to glass shown by archaeological site (Freestone 2003, Henderson *et al*. 2005, Leslie *et al.* 2006, Degryse and Schneider 2008, Degryse *et al.* 2010 a, Degryse *et al.* 2010 b, Henderson *et al.* 2010).

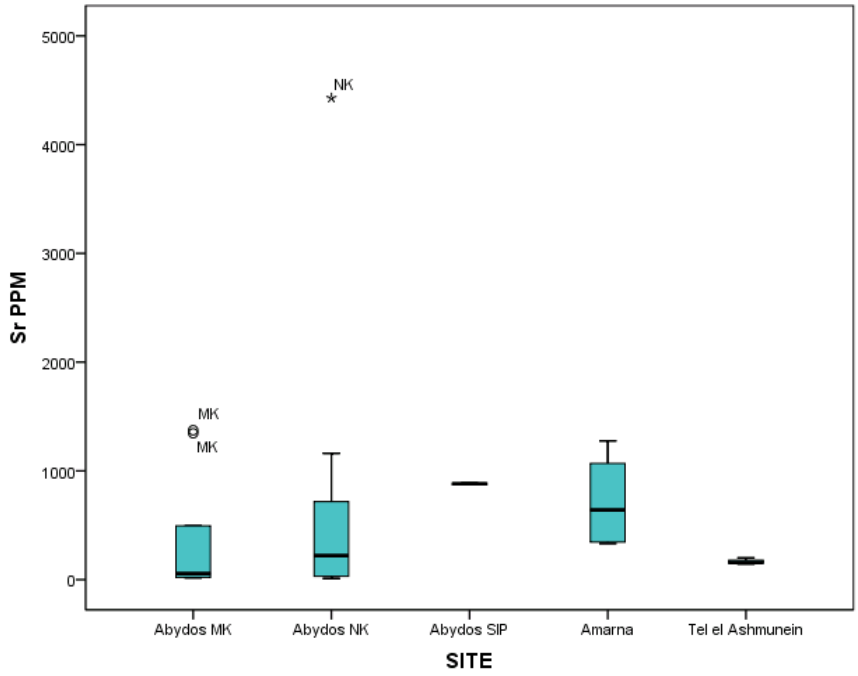


Figure 6.4: Middle Kingdom and New Kingdom concentrations (ppm) of Sr in Abydos faience in comparison to glass from Egyptian archaeological sites (Freestone 2003, Leslie *et al.* 2006, Henderson *et al.* 2010).

Strontium isotope analysis has the potential to be used as a tool for provenancing faience. This has been the aim of most of the strontium isotope studies on glass (Degryse *et al.* 2010 a, Henderson *et al.* 2010). This research hints that the same analysis could be conducted on faience. Most of the samples from this research have low strontium ratios and varied concentrations (in comparison with ancient glass). This corresponds with published findings on Egyptian glass. Degryse *et al.* (2010 a: 384) state that Egyptian glass has Sr isotope ratios that range between 0.70780 and 0.70793, which are very low (Figure 6.5). Three samples have higher Sr ratios than the above values (MK samples E9384-2 with a ratio of $^{87}Sr/^{86}Sr$ 0.70851, MK E2345-2 ratio of $^{87}Sr/^{86}Sr$ 0.70855, and NK E2375-6 with a ratio of $^{87}Sr/^{86}Sr$ 0.70805), which are similar to the results gained by Henderson *et al.* (2010: 7) for Mesopotamian glass, 0.70798 and 0.70871 (Figure 6.6 and 6.7 for Egyptian sites). All other samples are either below the expected ratios, or are within their limits. This may mean that three of the samples were made with raw materials of a different origin, possibly from a source in Mesopotamia. However, these results are tentative and indicate that it might be possible but there is a lack of base maps of the local area (Abydos) to make any such conclusions.

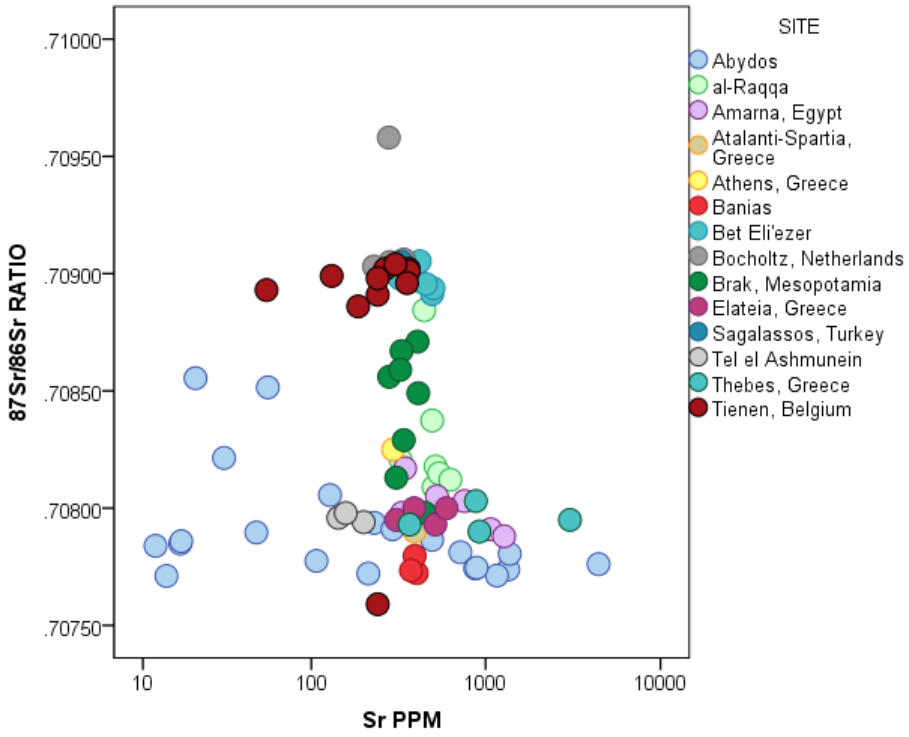


Figure 6.5: Sr ratio ($^{87}Sr/^{86}Sr$) versus concentration (ppm) of the Abydos faience and glass from several sites in the Mediterranean (Freestone 2003, Henderson *et al*. 2005, Leslie *et al.* 2006, Degryse and Schneider 2008, Degryse *et al.* 2010, Henderson *et al.* 2010).

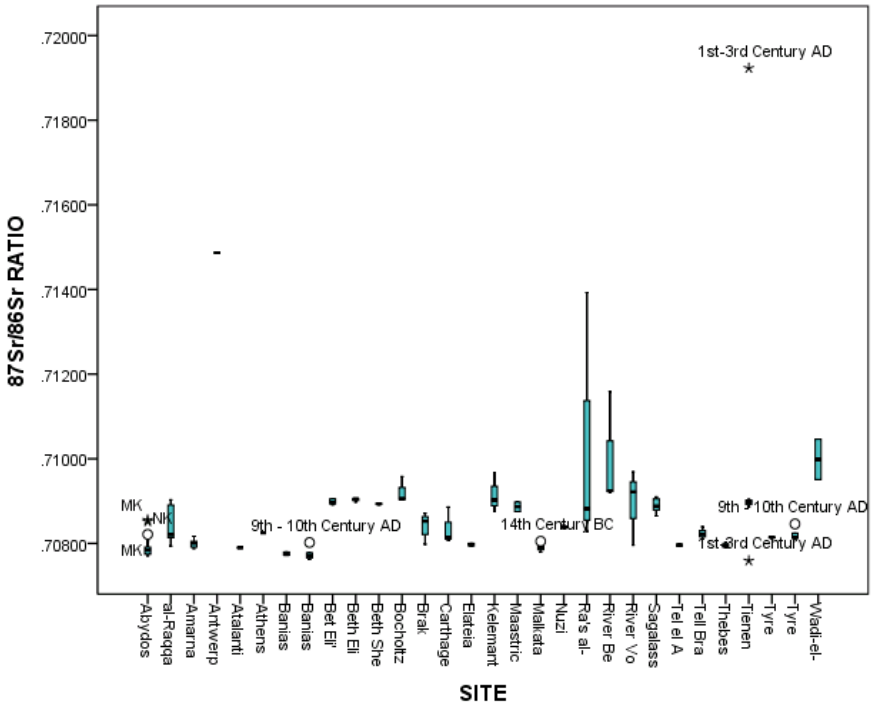


Figure 6.6: Sr ratio ($^{87}Sr/^{86}Sr$) of glass and Abydos faience by site and time period (Freestone 2003, Henderson *et al*. 2005, Leslie *et al.* 2006, Degryse and Schneider 2008, Degryse *et al.* 2010 a, Degryse *et al.* 2010 b, Henderson *et al.* 2010).

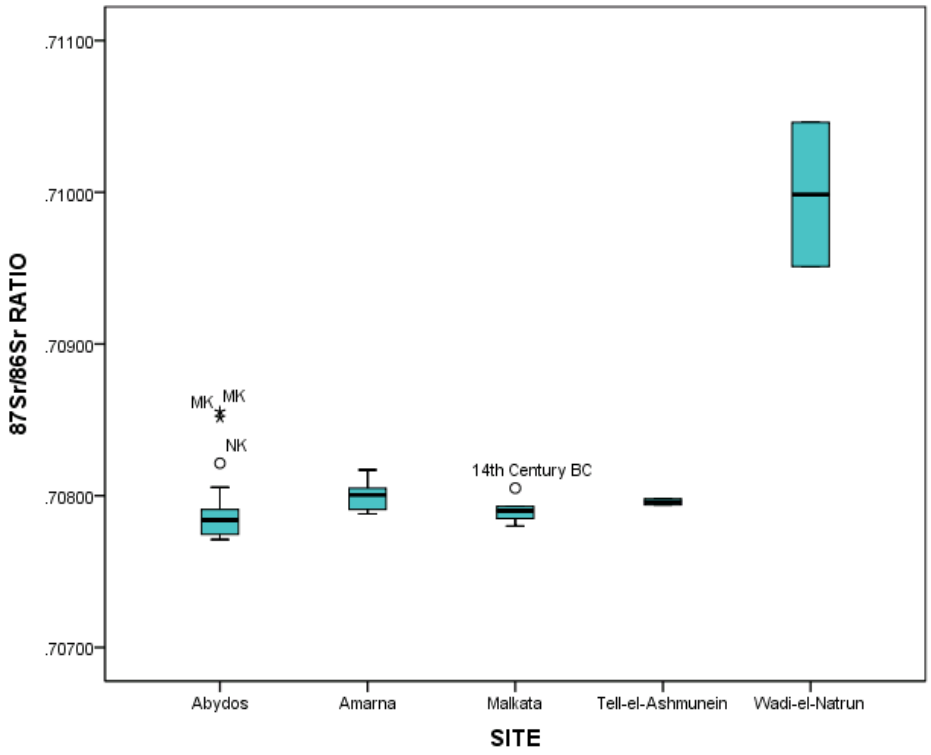


Figure 6.7: Sr ratio ($^{87}Sr/^{86}Sr$) for Egyptian sites and time periods (Freestone 2003, Leslie *et al.* 2006, Degryse and Schneider 2008, Degryse *et al.* 2010 a, Henderson *et al.* 2010).

6.4.3 Isotope By Time Period

In order to explore whether or not there is any variation in the strontium ratios and concentrations between time periods, the strontium ratio was plotted with the strontium concentration (Figure 6.8). However, no distinctive groups became evident, except that most of the Second Intermediate Period beads appeared to form a cluster, with one exception. This is due to the beads not being faience but actually Wollastonite. This was determined by SEM-EDS after the samples were analysed (Chapter 5, Section 5.4.3.2). The Second Intermediate Period beads were then removed from the plot to determine if their high concentrations were distorting the appearance of any distinctive groupings for the Middle and New Kingdom beads (Figure 6.9).

The Middle and New Kingdom beads have a much wider range in concentrations and ratios, and no distinct groupings resulted. This could be due to the sample size, or the extreme variety of the faience bead samples in the assemblage. There were so many unique beads of each type of faience in the sample assemblage that there may not have been enough of one type to create a statistical grouping.

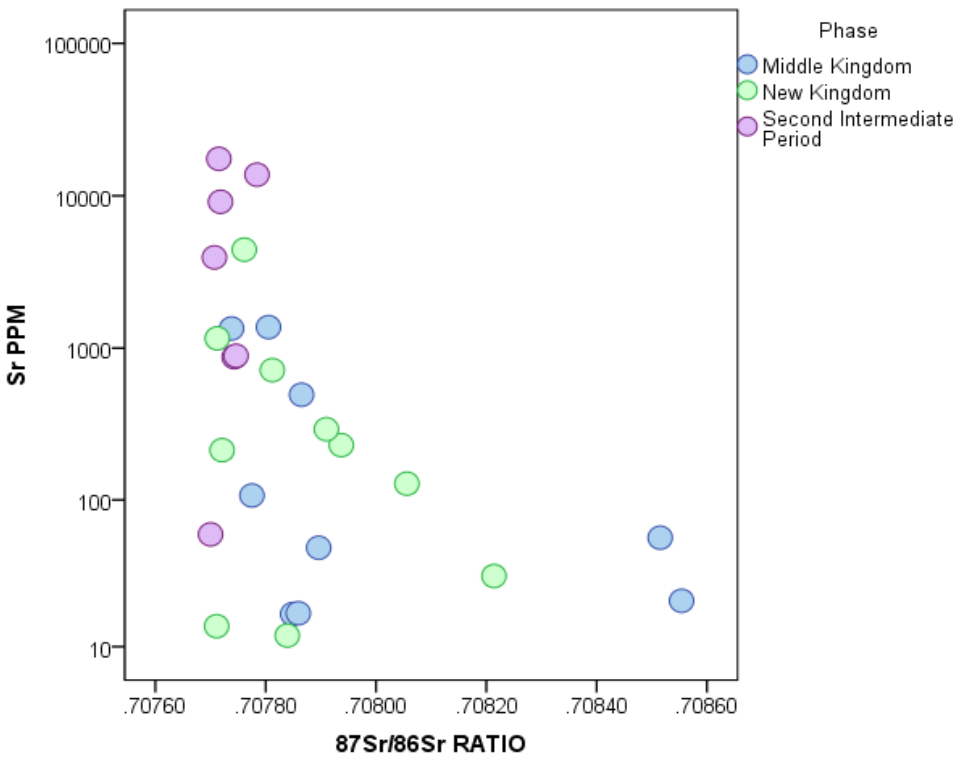


Figure 6.8: Sr concentrations (ppm) compared to the Sr ratio ($^{87}Sr/^{86}Sr$) based on time period.

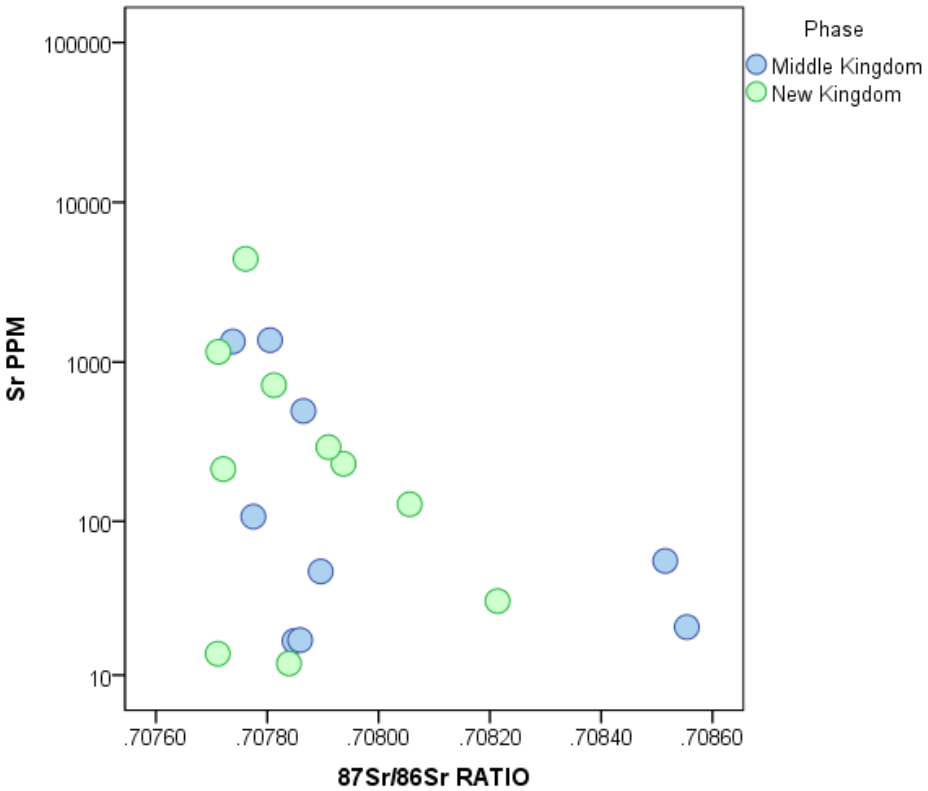


Figure 6.9: Middle Kingdom beads compared to New Kingdom beads by Sr concentration (ppm) versus Sr ratio ($^{87}Sr/^{86}Sr$) with no identifiable groupings.

6.4.3.1 MIDDLE KINGDOM AND NEW KINGDOM

The Middle and New Kingdom samples have a very wide distribution of ratios and concentrations. There are beads with very low levels, which indicate natron as a possible alkali source, because the ratios are very close to limestone ratios. This correlates well with the SEM-EDS results, as the samples with high levels of strontium also have large amounts of potassium and magnesium, which indicate plant ash as the alkali source (Section 6.5.2.1).

The Middle Kingdom beads have a stronger correlation of strontium concentration to calcium, since they were selected based on their calcium content. However, they still have a wide range of strontium concentrations (Figure 6.10). The New Kingdom beads do not have a significant correlation because they were not selected on the basis of their calcium content, as this was unknown at the time of sampling (Figure 6.11). As a result, the beads were selected based on colour, to represent the variety in the assemblage. Since the New Kingdom assemblages have such a large variety of faience colours, there appears to be a larger range in calcium values based on colour (Figure 6.12). Previous work by Shortland and Tite (2000) shows that (at least in the case of glass) certain colourants are combined with specific alkali sources, i.e. cobalt was paired with natron, and copper was paired with plant ash to make blue glasses. Therefore a correlation was run to compare the calcium percentage versus the strontium concentration based on colour, and it was found that there was no significant correlation, which suggests that there might be no such pairing occurring in faience technology (or at least in this sample set).

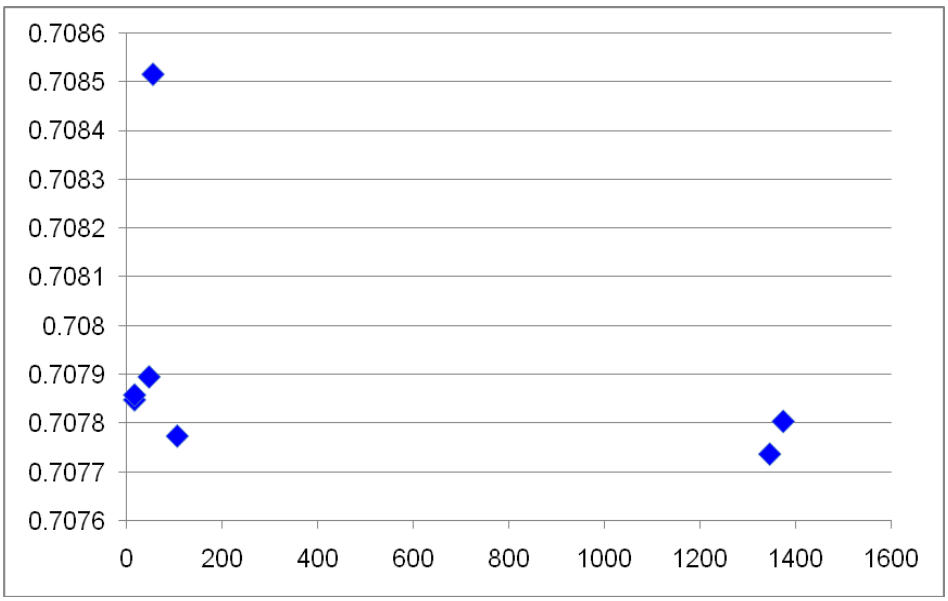


Figure 6.10: Middle Kingdom strontium ratios ($^{87}Sr/^{86}Sr$) versus strontium concentrations (ppm).

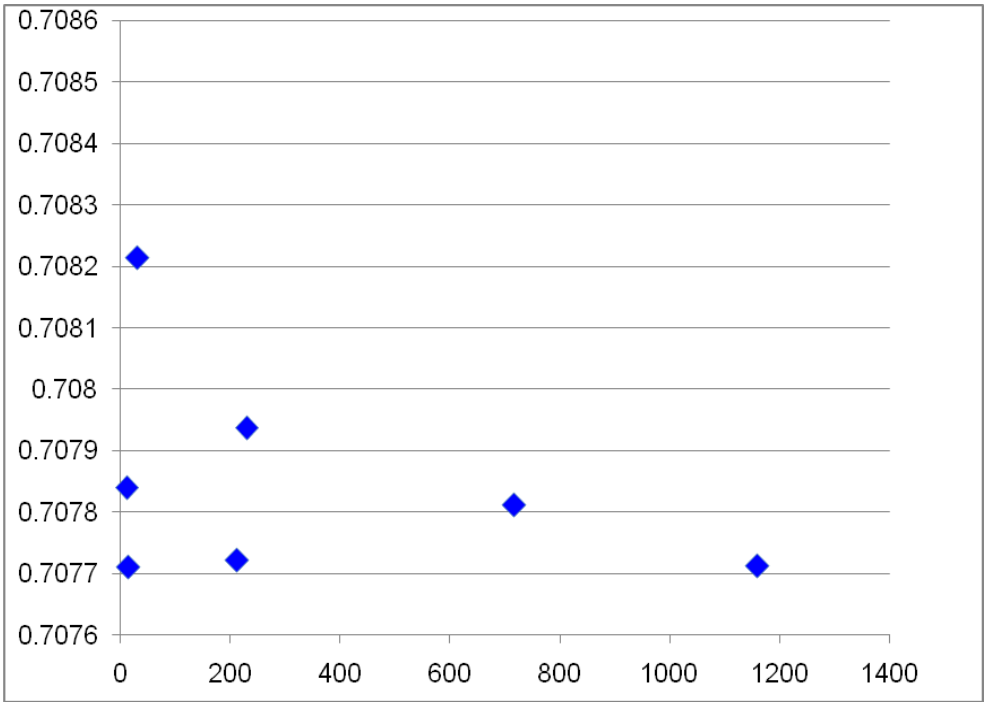


Figure 6.11: New Kingdom strontium ratio ($^{87}Sr/^{86}Sr$) compared to concentration (ppm).

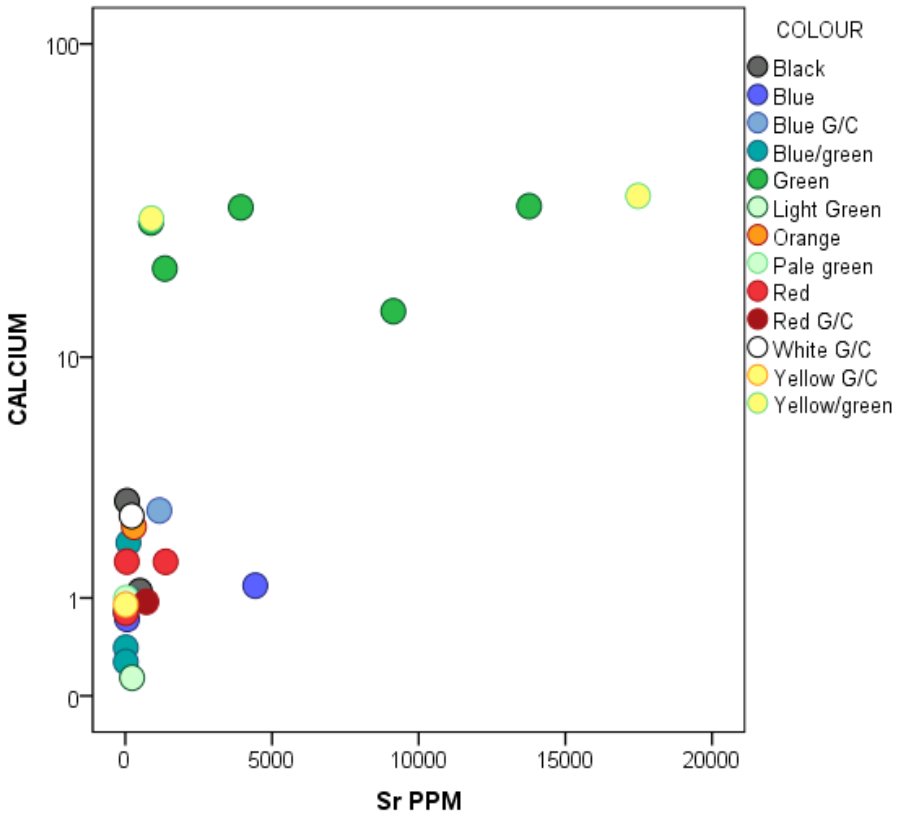


Figure 6.12: Comparing calcium percent to faience colours and Sr concentration (ppm) to determine if there is a relationship between the alkali and colourant used.

6.4.3.2 SECOND INTERMEDIATE PERIOD

As stated earlier, the Second Intermediate Period beads are made from a natural mineral, Wollastonite, and are therefore not faience (see Section 5.4.3 in Chapter 5). These beads have a different chemical composition, which is high in calcium (about 30%). Therefore these beads had some of the highest strontium levels of all of the samples, and the calcium to strontium correlation is good, indicating that the strontium came from the calcium source. The Second Intermediate Period beads show a restricted range of strontium with one exception (this one being faience), although the range of concentrations and ratios are still varied (similar to the Middle and New Kingdom) (Figure 6.13). The very high levels of strontium concentrations could be indicative of the alkali source being plant ash, as the strontium ratios are a good match to local limestone.

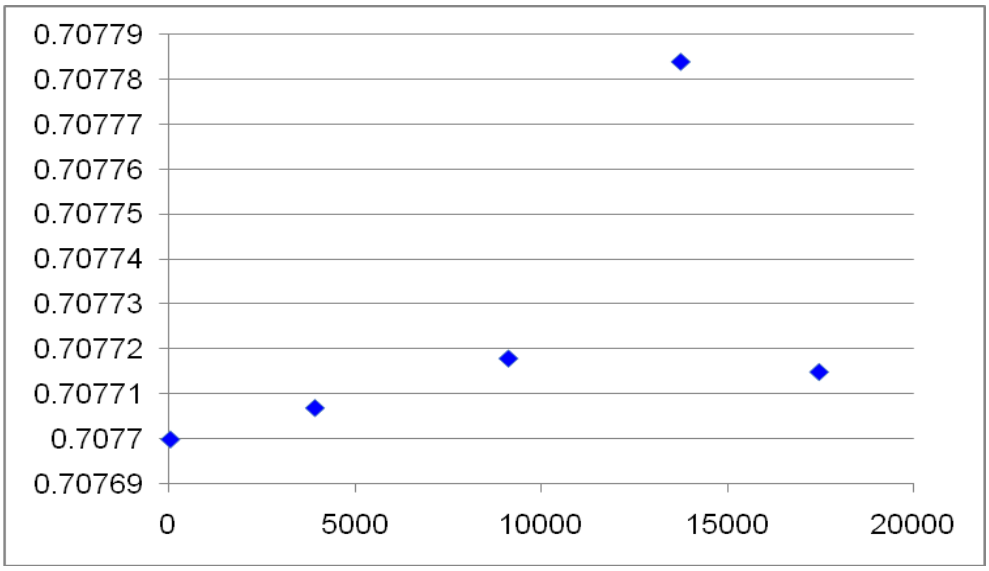


Figure 6.13: Second Intermediate Period strontium ratios ($^{87}Sr/^{86}Sr$) and concentrations compared (ppm).

6.5 Discussion

The discussion will be presented in order of the aims and objectives of this strontium isotope research, the first of which was the question of diagenesis and whether or not strontium isotope analysis was possible on faience material. The second was if strontium would be able to aid in determining the raw material sources of faience. Thirdly was if the origin of the raw material/faience could be determined, and finally if there is a difference between the time periods of interest.

6.5.1 Diagenesis

Diagenesis could affect the strontium levels of the faience samples, and increase them over time. It can be very difficult to distinguish between something made of local materials, and something that has fully re-equilibrated as a result of its local burial environment and the process of weathering. It should be pointed out, however, that precautions were taken to try to prevent this potential problem, in that the samples were cut and cleaned to avoid weathered areas, and then washed with dilute acid. In addition, the faience used in this analysis comes from tomb excavations, and funerary material tends to be subjected less to weathering, because the beads are not necessarily surrounded by soil. Some, for instance, could have been wrapped around a mummy in a sarcophagus, rather than buried in the soil. However, due to the lack of excavation notes, this might not be the case for all of the beads.

A small experiment was conducted on the largest of the beads (E2379-10), whereby the core and glaze materials were sampled separately. It emerged that the strontium concentrations and ratios for both samples were similar, which lends support to the argument that the results tabulated below reflect the primary composition of the sample. Either the beads are not diagenetically altered, or both core and glaze are completely altered. Another point that can be made is that there is a positive correlation with CaO and Sr, which suggest a primary relationship that has not been diagenetically altered.

6.5.2 Alkali

As noted above, both glass and faience contain two distinct groups, which relate to the question of whether the alkali source is natron or plant ash. Isotope studies of natron and plant ash glasses have proven to be successful in differentiating between the two types of alkali (Degryse *et al.* 2010 b: 83). Natron in glass or faience should have very little impact on the strontium levels, whereas plant ash is more complex and heterogeneous. Its signatures can vary depending on the soil where the plant grew, and the type of plant itself can provide a source of lime (Degryse *et al.* 2010 b: 83).

The main difference between glass and faience is the quantity of alkali present, because in faience this is relatively low. However, it is possible that some of the results from this study can identify the alkali and lime raw material sources. A few of the strontium concentrations indicate very well ashed plants (meaning the plants were thoroughly ashed before use as the alkali source, and have a very high

concentration of strontium) whilst others have very low levels, which could indicate the use of natron as the alkali source. Very high levels of strontium concentrations could also indicate the use of marine shell as the lime source, whereas the low levels would indicate limestone, which would have lower levels due to weathering. New Kingdom bead E2344-1 has a strontium concentration of 1160 ppm, and E2380-5 has a concentration value of 4429 ppm. Middle Kingdom beads E2383-6 and E2383-4 are also quite high at 1346 ppm and 1374 ppm respectively. The most likely source of alkali for these beads is plant ash, and the lime added to the faience material could be from marine biogenic carbonates. Other beads have very low levels of strontium concentrations, such as the Middle Kingdom bead E2379-10, which is around 17 ppm, and the New Kingdom beads E2384-5 and E2375-8, which have Sr concentrations of 12 and 14 respectively. These beads were probably produced with natron (or very low levels of plant ash) and possibly had limestone as the source for lime.

6.5.2.1 Strontium Isotopes vs. SEM Results

As mentioned in Chapter 5, a considerable amount of SEM analysis was undertaken to determine the silica, colourant, and alkali sources for all the samples represented in this PhD research (Appendix G and H). The specific SEM result of interest is the alkali source, and this now seems to tie in well with the results of the strontium isotope analysis. The vast majority of the beads analysed from all time periods have mixed alkali elemental and strontium signatures, with a few variations. Four beads (E2345-4 (MK), E2383-6 (MK), E2344-1 (NK), and E2380-5 (NK)) seem to have very high plant-ash levels based on their strontium analysis, which would lead to the conclusion that the alkali source was plant ash. This is supported by the SEM results for these beads, which show very high potassium (correlated with plant ash), comprising averages of 1.25% for E2345-4, 0.78% for E2383-6, 3.02% for sample E2344-1, and 1.48% for E2380-5. The beads with very low Sr concentrations all had low levels of potassium (E2379-10 had 0.29% and E2375-8 had 0.31%). There was only one exception, bead E2384-5, with a potassium level of 1.31%, which is quite average and could perhaps have indicated a flaw in the study. However, when this bead's chemical composition was inspected further, it was found to lack magnesium, which is one of the main elements associated with plant ash. Therefore this bead is probably made from natron, suggesting that the strontium isotope analysis and SEM results support each other very well.

6.5.3 Provenance

The $^{87}Sr/^{86}Sr$ ratios of faience in this project are compared with the published research on glass, and there seems to be some tentative indication that strontium isotope analysis could be successfully used to provenance faience. However, this is tentative and only indicates the possibility with further work needing to be conducted. Most of the faience beads fall within the strontium ratio for Egyptian glass (or have even lower ratios). These beads could prove to have been produced in Egypt or from Egyptian raw material sources. On the other hand, three beads match ratios outlined by Henderson *et al.* (2005: 672) for Mesopotamian glass, and could indicate importation of faience or raw materials (Middle Kingdom bead 9384-2 with a ratio of 0.70851, Middle Kingdom bead E2345-2 ratio of 0.70855, and New Kingdom bead E2375-6 with a ratio of 0.70805). However, it should be repeated that this interpretation is based on glass artefacts, and that these artefacts could have been made with different raw material sources than faience, even if both were found at the same site.

The difficulty with provenance studies is that there are many variables among the raw materials and their sources that are difficult to tackle. Some of the results from this study are promising. Some may reflect weathering and ground water interactions. The very low levels could represent the lack of interparticle glass, which is common in faience made by the cementation glazing method. However, as noted above, bead E2379-10 could discredit this explanation, as the core and glass was analysed separately with the same results. This suggests that the other analyses are representative, and that there is little difference between the glaze and the core. Also, a correlation between the glazing method and the results of both strontium concentration and ratio was undertaken with a null result, meaning they have no effect on the strontium present.

The solution to unravelling faience provenance, and discovering whether the interpretations above are true for all faience, is to undertake further analysis. As Henderson (2009: 136) states, 'the challenge comes in being able to state categorically that the combination of raw materials used to make the glasses on those sites were not repeated elsewhere, leading to similar chemical compositions and to overlapping compositional 'groups''. This can very well be true for faience: only upon the completion of a considerable number of studies will researchers be able to differentiate the source of raw materials from the source of the finished product. However, it is also likely that the infinite number of variables will hinder such work, and it is possible that only general conclusions can be reached.

The site of Abydos is located very close to limestone, chalk, and shale cliffs, which were created in the Tertiary. The Pleistocene deposits at the site also include quartz sand (yellow and white), which could have been utilised for the silica raw material source. Difficulty lies in the fact that the majority of ancient Egyptian cemetery sites have similar geological features, which could mean that pinpointing a provenance for the location of manufacture could be difficult within the region itself, and might therefore need to remain as a more general geographical area. On the other hand, a fundamental difference may exist between the Delta and Upper Egypt. It is therefore possible that, with additional and better-recorded samples, a provenancing study could be accomplished, although it would require a large number of samples from across Egypt and the Near East to generate a database that can be used for comparison. Therefore, provenance studies for faience are not currently viable with the data discussed in this thesis, but the potential for such work seems to exist.

6.5.4 Middle Kingdom vs. New Kingdom Results

The strontium isotope results for faience material are far more variable than expected when compared with the published range of glass of the same period. Egyptian faience displays a wide range of strontium concentrations (12-17000 ppm) and a relatively restricted range of Sr isotope composition ($^{87}Sr/^{86}Sr$) (0.7075-0.7085). However, two trends were observed in the data: 1) high strontium concentrations with low strontium ratios, and 2) low strontium concentrations with variable strontium ratios.

The first trend predominantly represents the Second Intermediate Period beads, which have an unusual mineralogy (high calcium) and therefore have high strontium concentrations (Henderson *et al.* 2010: 14). The one exception is a Second Intermediate Period bead, E2385-1, which only has 59 ppm, and is the only non-Wollastonite bead sampled from this time period (Chapter 5, Section 5.4.3). Limestone and shell have concentration levels over 1000 ppm, although a few of these beads have much higher levels. This could be due to very well ashed (concentrated) plant ash as the alkali source. Henderson *et al.* (2005) recorded levels in glass to 1000 ppm. This is supported by the ratios being close to/within the predicted range for limestone found in Egypt (up to 0.7086).

The second trend is composed of the Middle and New Kingdom beads. These beads have lower strontium concentrations (below 50 ppm), which have not been found in glass. This argues for a very low calcium/strontium production, meaning that some of the faience beads could have been produced with natron.

Pure natron could produce an alkali source that is strontium free, and therefore the concentrations would be low.

Overall, the strontium isotope analysis supports the conclusion reached in previous chapters, that the Middle Kingdom and New Kingdom beads are quite similar in overall composition and production methods. The vast majority of the samples were made with a plant ash or a mixed alkali raw material (both plant ash and natron), with very few exceptions. The strontium isotope compositions of the Middle Kingdom and New Kingdom beads are more or less similar, suggesting production in the same part of Egypt, with perhaps three exceptions as stated above. Again, these samples demonstrate the overall consistency of this bead assemblage, and indicate that faience technology may have varied in terms of colours, but there is little chronological change in composition. It would also be useful to look at similar Middle Kingdom and New Kingdom assemblages from one or two other sites, such as Thebes or Lahun, to see whether the same pattern occurs at sites beyond Abydos.

6.6 Conclusion

This pilot has demonstrated that strontium isotope analysis of faience presents a much greater variation in compositional range than ancient glass. An aim was to determine if there was enough strontium in faience to be analysed, and if so had it been affected by diagenetic alteration, since faience is less resistant to weathering than glass due to its structure. This aim was achieved, there was enough strontium and it represented the original strontium concentration as determined by two methods. The first, SEM-EDS shows the alkalis are well preserved due to the wide range of values. The second was that the faience in the samples have not homogenised to a diagenetic signal as displayed by the Middle Kingdom ball bead 2379-10, which had the same strontium concentration and ratio results for the interior and exterior of the bead.

The second object of determining the raw material sources for the alkali used in faience was successful. The strontium analysis results of the faience were consistent when compared to ancient glass results and indicate that most of the faience beads were made with plant ash as the alkali source. The SEM-EDS results of the same samples are consistent with these findings, with the conclusions on the raw material sources being similar.

The results relating to the third objective hint at the possible origin of some of the faience beads. The strontium ratios indicate that all but four of the faience samples were produced using local limestone, and therefore it can be reasonably

assumed that they were locally manufactured. The other four samples could be from the Near East. However, this should be treated with care, as much more work needs to be conducted on faience material and the local area, such as potential sources of lime and how the different quantities of added lime will affect the strontium ratios.

The last objective was to ascertain whether or not there is a variation in the isotopic values from one period to the next. This research has proved there really is no variation, as both the Middle and New Kingdom have similar results falling within one of the two trends, having low strontium concentrations and variable strontium ratios. The Second Intermediate Period samples are the second trend and have high strontium concentrations with low strontium ratios. These beads are more consistent and have a narrower range, due to being made of Wollastonite rather than faience (with the exception of one faience example). The strontium isotope analysis and SEM-EDS have shown that the Middle and New Kingdom beads were produced with similar manufacturing methods. This highlights a general lack of variation in the production methods utilised in faience production at Abydos. This will be discussed further in the next chapter.

Chapter 7: Experimental Archaeology

7.1 Introduction

This chapter presents two aspects of this PhD research that are related to experimental archaeology. The first of these was replicating faience based on the results and conclusions drawn from the SEM-EDS analysis, in essence reverse engineering faience beads. The second was the application of new analytical methods never before utilised on faience material and their development and use on archaeological samples. These two aspects were undertaken to answer questions, which came up during the initial inspection and SEM-EDS analysis of the faience beads, which include several key questions regarding hardness, quartz, and iron:

- Why did the hardness of the beads vary? Was this due to firing conditions?
- Why were there iron 'prills' within the matrix of some of the beads? Was this due to firing conditions, such as a reduced atmosphere, and high iron content?
- Is there another way to prove that quartz pebbles were used instead of sand or vice versa?

An attempt to answer these questions will be presented in this chapter with the use of some experimental analytical methods (crystallography (CL) and electron backscatter diffraction (EBSD)) and established methods such as Mohs hardness. The first section of this chapter will present the background to experimental archaeology and the attempts to replicate faience. This will include a discussion and presentation of the SEM-EDS results of the experimental beads themselves. The second portion of the chapter will present the background, methods, and the results of the CL and EBSD analysis. The final section will present the conclusion of all the experimental work and discuss what the results mean for faience in general.

7.2 Background of Past Experiments

As mentioned in Chapter 2 (Section 2.1.4.2), several different researchers have undertaken experimental archaeology. Binns *et al.* (1932) attempted to determine the recipe for faience, as did Lucas (1962). Noble (1969) conducted glazing experiments. Wulff *et al.* (1968) studied the Qom (cementation) glazing method in Iran. Vandiver (1982) and Tite *et al*. (1983: 17) attempted both cementation and efflorescence glazing experiments. More recently La Delfa *et al.*

(2008: e113) and Eccleston (2008: 33) continued such work, the former on glazing methods and the latter on firing faience in ovens at Amarna, Egypt. All of the preceding experimental work was undertaken on faience to study specifically the glazing technologies, firing temperatures and conditions and raw materials used.

The reason why so many researchers have been interested in faience is what makes it difficult to study in the first place. There are no written records from the ancient Egyptians or from the ancient Near East, which describe the recipe for faience material or the craftsmen who produced it. All that remains are references to 'overseers of faience workers' (La Delfa *et al.* 2008: e114, Nicholson 2007: 146, Gordon 1993: 75). The only recourse left for the archaeologist is to undertake experimental work to attempt a better understanding of the technological challenges faced by the faience craftsmen.

These experiments enabled researchers to learn the craft by practicing it step by step (Vandiver 1998: 121). The practical experience of trying to work the faience paste manually gives a better understanding of the material than just reading about how difficult it is to work. Also, as stated by Wisseman and Williams (1994: 4), experimental archaeology "forces the scholar to work through a technology step-by-step without skipping phases as one inevitably does when merely visualizing that technology." The process of going through each choice and action that the craftsmen faced will aid in understanding the whole process more (Freidel 1993: 44, Martinon-Torres 2008: 29, Sillar and Tite 2000: 3). These choices include the type of silica resource to use, whether to use alkali or copper, at what temperature the material should be fired, and for how long.

This research intends to build on the large body of previous experimental work, and to address the additional questions highlighted above. It also provides the opportunity to test some of the hypotheses from previous research. However, the overall objective of this chapter is to take the results and conclusions of Chapter 5 and test them by replicating the beads and analysing them using SEM-EDS. The results from both archaeological and experimental faience beads will then be compared with each other to determine if the replicas are accurate representations of the production methods used to produce the artefacts.

7.3 Experimental Faience Production

The experimental work undertaken for this research attempted to replicate faience to match the archaeological samples analysed by SEM-EDS. However, the raw materials used by the ancient craftsmen were not available, so modern chemical supplements (in the case of sodium and calcium) were used, along with a

modern furnace. Several different types of silica and copper sources were used to determine which was best at creating the results produced by the archaeological samples.

During this research experimental replicas were produced in a furnace in order to test the firing conditions with limited variability, such as fluctuations in heat. Unfortunately, actual firing within replica kilns was not conducted. It is hoped that such studies will be carried out in the future, partnered with the same analytical methods to test them.

Forty-four batches of faience replicas were produced using different raw materials, production processes, colourants, firing temperatures and durations. Every batch was unique, as one or more of these variables was altered with each new batch. The results of the most significant research defining batches will be discussed below, based on the general production stages of faience, and as a running narrative of the questions that were asked during the undertaking of this research. The recipes for all 44 batches can be found in Appendix J, with a more detailed summary on key batches and specific beads selected for SEM-EDS analysis in Appendix K, and a diagram of the SEM moulds in Appendix N.

The most successful/informative batches were analysed with SEM-EDS and the results of this analysis will be presented throughout this section, where significant, and where a comparison to the archaeological results are necessary. All of the samples were prepared in the same way as the archaeological samples (in polished section) and SEM-EDS was used in the same way to determine the production methods and chemical composition. Although what has gone into the faience batch is known, it is necessary to see how it is represented in the SEM-EDS results and whether or not 'dilution correction' (where a paste differs compositionally from the finished product) should be undertaken (Baxter 2001: 132). All SEM images of the significant experimental faience batches are presented in Appendix L, and all of the raw EDS analyses for the same batches are presented in Appendix M.

7.3.1 Raw Materials

The first step in faience production is the selection of the raw materials. Subsequent steps include the mixing of these (based on glazing method), the forming of the samples, the glazing of the material (if application) then the drying and eventual firing of the faience (the next few sections) (Sillar and Tite 2000: 4, Miller 2007: 13).

The raw material composition was based on weight. The first batch of faience was made with 90g of silica, 3g of calcium, 4g of sodium and 3g of copper.

This recipe is close to the archaeological samples and typical faience in the quantity of each element present, while making it easier to calculate the recipe by weight percent. However, each batch was slightly varied to test the results of different recipes and the quantities of each element often changed.

7.3.1.1 Silica

Silica is the main constituent in faience (92-99%) and as such was treated as the main element of choice in the experimental samples (90% in most batches (Nicholson 2007: 134). Several different raw material sources were tested, such as: Japanese Garden Centre Pure Silica Sand, a local Ainsdale high iron sand (both wet and dry varieties), Mineral Marketing high silica sand, Pilkington imported sand from the Sinai, Egypt, and quartz pebbles from Cheshire.

The pure silica sand from the Japanese Garden Centre (JGC) achieved the best visual results. The samples were vitrified, bright, and the closest to a glossy glaze seen in any of the other beads (Batch 15, Appendix K). This silica source was used for twelve different batches with many different outcomes. However, it remains as the favourite for this experimental work. The use of a pure silica content sand improved the glaze's appearance and durability.

The sand from Ainsdale, near Liverpool, has a high iron content and because of this was used in several of the experiments to replicate the formation of iron prills in the archaeological beads (discussed in Section 7.3.5.2). Both wet and dry sand was used from this site. The wet sand contained seaweed and other impurities, as it was collected at the tidal line. This sand was coarse grained, whereas the dry sand represents dune sand with finer particles and less vegetation and other impurities. This sand was used in Batches 2, 4, 6, 11, 14, 16 and 17 before it was decided that the sand was not producing the desired colour or glaze characteristics seen in the archaeological samples. The high Iron content changed the intended colour of blue to a very dark greenish colour (Batch 17, Appendix K).

Mineral Marketing provided several kilos of Chelford (CH52) sand, which is a product they commonly sell to glass making companies such as Pilkington. This sand typically has a silica content of 97.3% with trace elements of iron, aluminium, and potassium. The Chelford sand is very similar to Egyptian sand with these impurities (with the exception of potassium). This sand is sourced from Lower Withington, Cheshire, from a glacial deposit of the Pleistocene Period. The average grain is rounded and has a particle size of 267 microns. Batches 21 to 25 were produced using this sand. However, there was no presence of any glaze at all. The

exterior surface had been coloured by the copper but had not vitrified. Therefore, the use of this type of sand was discontinued.

The Sinai sand became the second most preferred for experimental work, not because of the results, as they were very similar to those of the Chelford sand, but because of the raw material source. It was the only raw material used in this research that came from Egypt, which is significant because it had the potential to produce similar results to the faience beads from the same geological source, especially if isotope research were to be carried out for comparison. Another similarity to the Chelford sand is that this sand was imported by Pilkington for modern glass manufacturing and therefore is high quality silica sand. The results from the use of this sand as the silica source were very good. There was a lack of a glossy glaze (as with the Chelford sand), although the faience beads were similar in appearance to the archaeological faience samples. It should be noted that the lack of glaze is not necessarily due to any deficiency in the silica source, as this would be closely tied to the alkali source, which enables the vitrification of the silica particles. Both the Chelford and Sinai sand are excellent sources for experimental work, however better results seemed to be achieved with the Japanese Garden Centre's pure silica sand. This is understandable, because a better glaze is produced with a higher quantity of silica. Ancient Egyptian craftsmen did add high quality silica to some faience material as a second layer to produce a very glassy glaze (Nicholson 1998: 55).

An attempt was therefore made to use quartz pebbles as the silica source. The pebbles were collected from Eddisbury Hill, Cheshire where a natural sandstone outcrop with natural quartz is present. These quartz pebbles were fired in the furnace at 950^0 for five hours (the average time of faience firing conducted for this research) (Eccleston 2008: 33). Once the pebbles cooled they were then crushed easily in a mortar and pestle down to a powder of 50-100 microns (using sieves to gauge size). The batches of faience made with this raw material source (Batch 37 and 38, Appendix K) were the first effloresced glazed beads to have a whitish core and a blue exterior. The glaze colour spread to the body of the bead in almost all of the other experimentally effloresced samples. This is of course due to the colourant being mixed in with the core material and left to effloresce out of the bead. It is not known why the core remained white for these beads, and this has created further questions: does crushed quartz pebble allow for the copper to migrate better, or were the firing conditions different in some way? These questions will hopefully be answered in the future with further experimental work. Overall,

though, the results for the quartz were excellent, if labour intensive and time consuming.

The experimental beads were subjected to SEM-EDS analysis and then a comparison with the archaeological material was conducted with SPSS. The results show, in the case of silica plotted against calcium, that the vast majority of the experimental samples contain around the same levels of these elements as the archaeological ones (Figure 7.1). The experimental faience with 5% calcium are at the very edge of the group of archaeological faience which contain less than 5% calcium. This may indicate that the lime in the archaeological samples was not added deliberately but as an impurity in very little quantities. This will be discussed further in the next section.

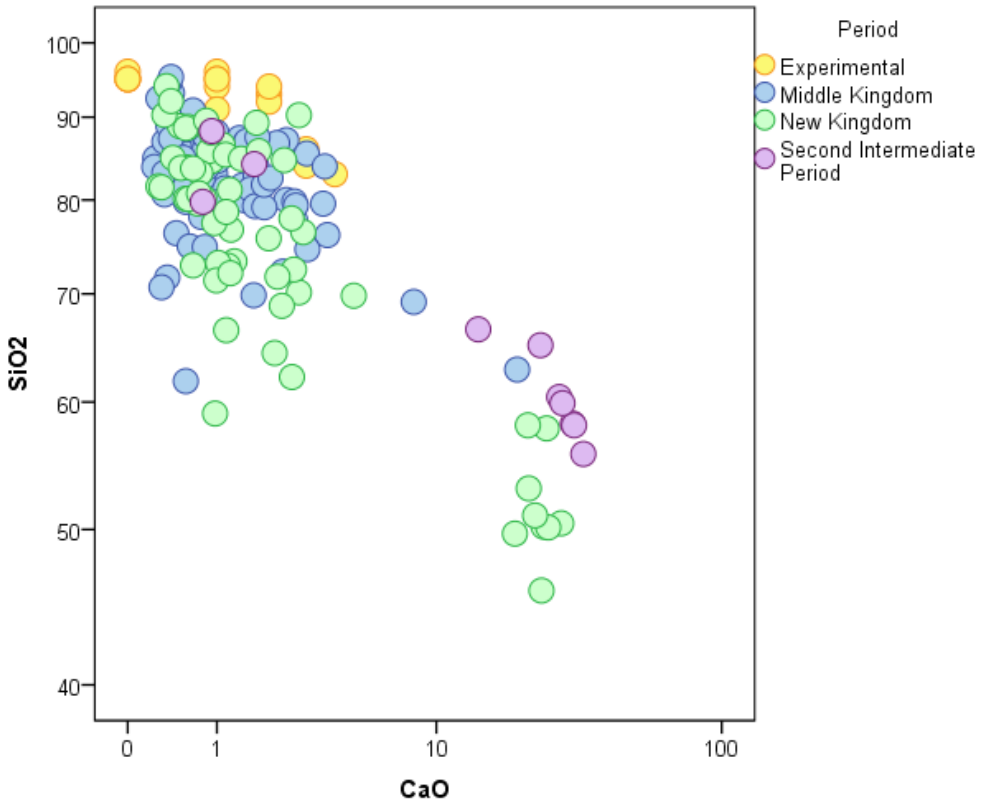


Figure 7.1: Experimental samples compared to archaeological samples based on silica and calcium content.

The experimental faience beads were also compared to the archaeological faience beads by silica and iron content (Figure 7.2). There were only two experimental samples that had high iron content: Batch 17, which was produced with the Ainsdale high iron sand, and Batch 36, which was produced with the high

iron colourant chalcopyrite. Both of these beads may be considered as outliers from the rest of the experimental beads in Figure 7.2.

As Figure 5.24 demonstrates, these beads from Batch 17 and 36 fall between the line of the higher iron content and the point at which the colourants play a factor (iron versus copper). As the bead from Batch 17 is blue and the one from Batch 36 is olive greyish green, they fall more on the copper coloured side of the graph, whereas the high iron content brown and reds remain on the other side of the spectrum. This could indicate that the archaeological samples around these beads are either made with sand with a high iron impurity, or with a mineral iron rich copper source such as chalcopyrite.

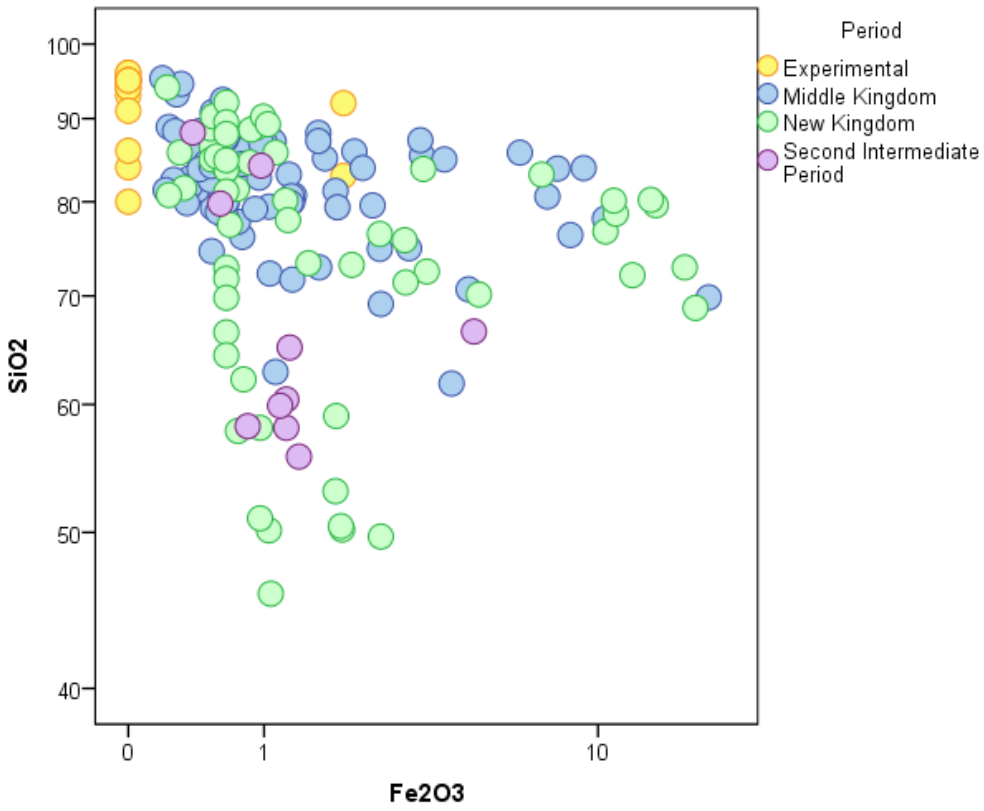


Figure 7.2: Comparison of silica and iron for both experimental and archaeological faience beads.

7.3.1.2 LIME AND SODIUM

Since the experimental work was undertaken outside of Egypt, the raw materials were sourced from commercial suppliers. Therefore in the case of lime and sodium, modern commercial chemicals were used as supplements (everyday Granular Garden Lime and TATA Chemicals Anhydrous sodium carbonate and bicarbonate).

On average archaeological faience is comprised of about 1-3% lime, which can be introduced with the silica component (sand) (see Figure 7.1) and/or the alkali (plant ash) (Figure 7.3), or added deliberately as crushed limestone (Nicholson 2007: 135). Due to a variety of silica sources being used for this research, lime was always added at 1-5% to ensure its presence in the replica samples (since some of the silica sources lack lime). The amount of calcium is consistent with the amount found in the archaeological samples and cluster together (see Figure 7.1). The samples with 5% added calcium are at the very edge of the cluster, which means the addition of this much lime was perhaps a little high, but still within normal parameters for this faience assemblage. However, one variation of the experimental samples compared with the archaeological ones is that they are consistently higher in silica content. The experimental faience beads seem to be the cap of the cluster with a few archaeological samples at similar levels.

Even though there are three ways in which the calcium could have been added to the archaeological faience, for this research it was added intentionally to meet the deficiency in the relatively pure silica sources, and because no plant ash was used in the production of these faience beads. Therefore, when the calcium and potassium content were compared with each other, and the archaeological and experimental samples plotted, it was expected that the experimental samples would be near zero for their potassium content and, at most, at about 5% for calcium. Of interest are the three batches with higher calcium content, including Batch 17, which is the Ainsdale wet sample, which contained seaweed and other impurities. This would explain the potassium levels, because seaweed is relatively high in potassium, and has been previously used in experimental research on vitreous materials to simulate plant ash alkalis. However, Batches 15 and 19 also contained potassium, which indicates that the Japanese Garden Centre silica was not as pure as was expected. The other raw materials in these batches were used in other samples that did not produce potassium, which indicates that the Japanese Garden silica must have been the source. This could explain why Batch 15 turned out so well, for the potassium would have lowered the firing temperature of the silica to form the glassy glaze.

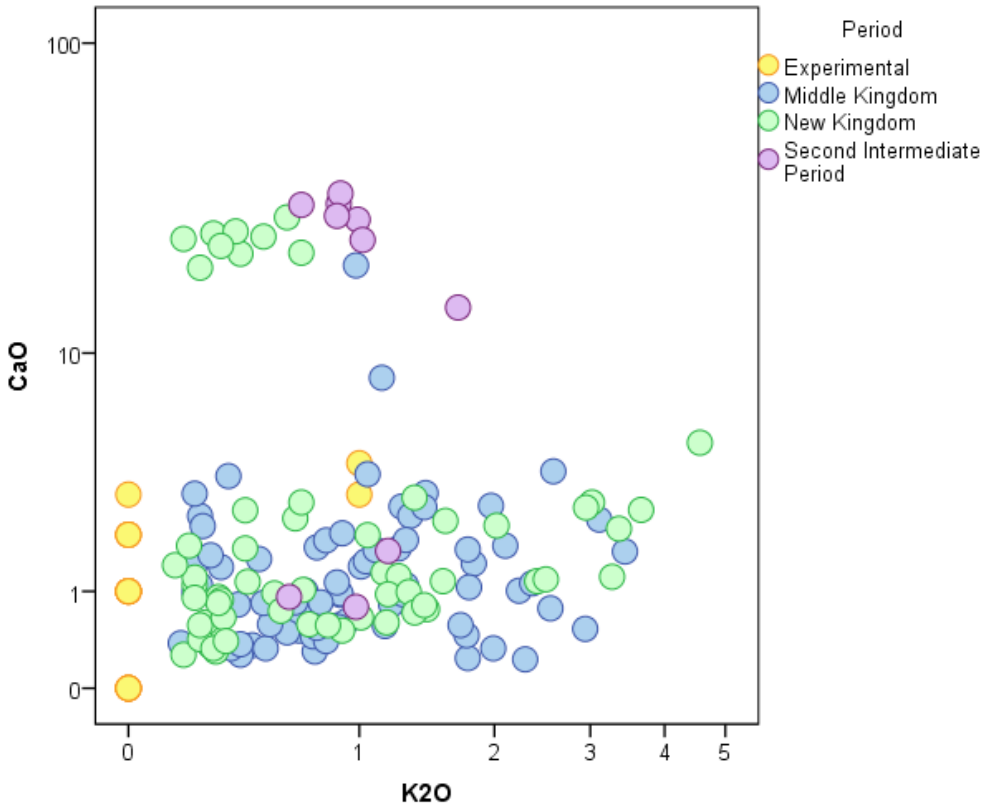


Figure 7.3: Experimental and archaeological faience samples, calcium and potassium content compared.

TATA Chemicals Anhydrous sodium carbonate and bicarbonate was used for this research. This is a light grade (100 +/- 20 median average size (microns)) that is often used for the modern glass industry. As sodium is present at about 0.5-3% in archaeological faience, 1-5% was added to the experimental batches (Nicholson 2007: 135). The quantity of sodium was varied in several different recipes to see if the quantity affected the results. Tests showed that the quantity of sodium barely affected the outcome. Batch 15 had the second highest sodium average (6.31%), which could have helped produce the glaze. However, Batch 36 had the highest sodium average (7.6%) and the glaze was not especially good. It should be noted that less than 5% sodium was added to these batches, but the average EDS result per bead was higher. This is due to the method of analysis, as spot analysis records the variations between spots, but avoids the main component of silica. The lower levels of sodium could have burned off during analysis, but this is not likely to have had a significant effect, as concluded in Chapter 5.

Figure 7.4 shows the comparison of the sodium content with potassium content. This graph was generated to isolate any archaeological samples that could

be classified as natron. The hope was that if any samples coincided with the pure sodium samples, they would have been produced with natron. However, no archaeological samples correlated and therefore the argument of mixed alkali or plant ash as the alkali sources holds for the archaeological samples. Also, the same three batches mentioned above (Batches 15, 17, and 19) seem to conform to the archaeological samples. Since these three batches have sodium and potassium, they would be classified as a mixed alkali, and therefore the archaeological samples in their vicinity could be too.

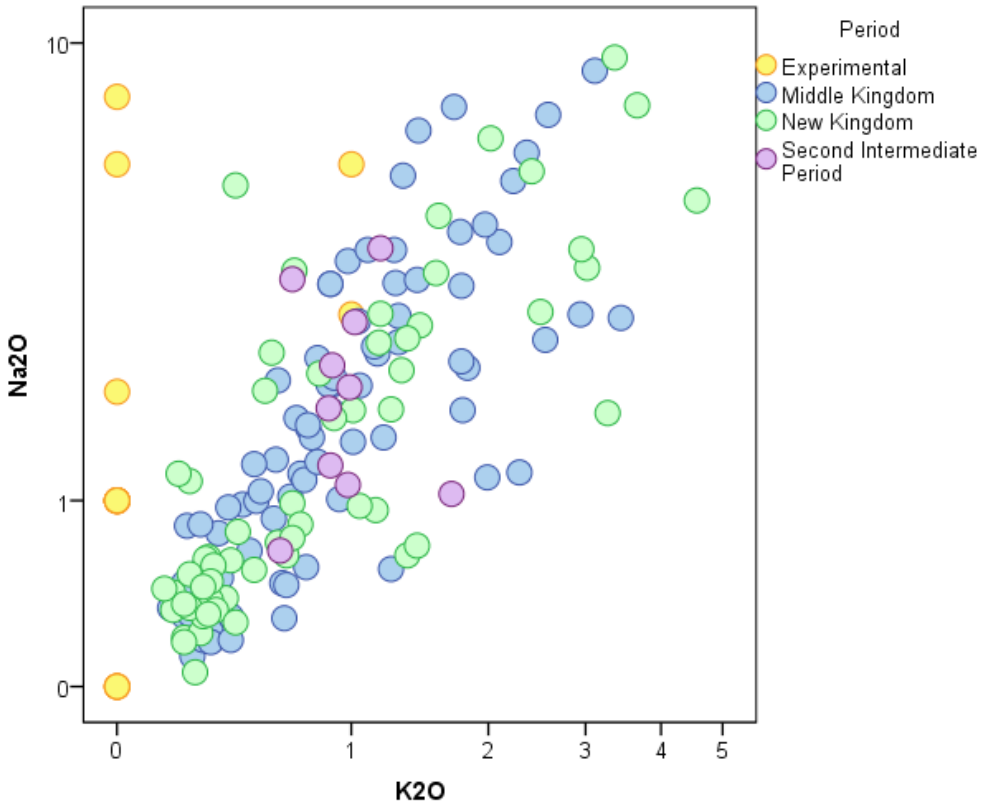


Figure 7.4: Sodium content compared to potassium content of faience samples both experimental and archaeological.

7.3.1.3 COPPER

Copper is one of the main colourants used in faience production from the beginning of the Predynastic period to the very end of its production in Egypt. Copper is normally present in quantities of less than 5%, and this was matched in the experimental samples. The source of the copper has still not been identified with certainty. There are quite a few options, for example copper-alloy metal scraps, which can be detected by the presence of impurities such as tin (see Chapter 5

Section 5.4.3 for more detail) (Nicholson 2007: 135). There is also the possibility of mineral sources such as malachite and azurite (Tite and Shortland 2008: 51).

Each experimental batch contained between 0.5% and 5% copper. The experimental research investigated the use of both copper metal scraps and mineral sources. The first copper source was an old kitchen pipe, which was filed to create copper dust; this was then added to the batch recipes. However, as this took a considerable amount of time to produce, AnalaR grade cupric oxide was utilised for some batches. The copper mineral sources were malachite and, as mentioned earlier, chalcopyrite. These minerals were selected for two different reasons: malachite because of the previous research published about its use, and chalcopyrite because it also contains iron and was therefore used to investigate further the iron content of some of the archaeological faience beads by attempting to replicate some of the iron prills in the faience matrix.

The metallic copper filings produced a blue colour, which was very similar to that of the archaeological faience. However, the colour was very spotted, and not homogeneous, with dark blue spots on a surface of whitish blue (Batches 15 and 19 Appendix K). The cupric oxide was then tested, as it was already a powder with a particle size of about 22 microns. This mixed very well with the other ingredients to form a homogenous blue colour (Batch 26 and 40 Appendix K). However, the blue from the cupric oxide was not as close in colour or shade as that produced by the metallic copper, which then became the preferred copper source. The copper mineral sources were also inaccurate in colour compared with the archaeological samples. Malachite produced a purplish blue colour (Batch 35 Appendix K) and chalcopyrite was a greenish grey (Batch 36 Appendix K).

7.3.2 Mixing

After all of the raw materials were acquired, the ancient Egyptian faience craftsmen could have mixed them together in two ways, either by hand, using pounders and quernstones (Nicholson 2009: 2) or, according to Stocks (1989, 1997, and 2003) they could have been premixed as dust from the stone-working industry. The first method of mixing would have depended on the glazing method. For cementation, the core of silica would have been formed and then buried in the glazing powder, which consisted of silica, lime, alkali, and the colourant. For application, the core would have been dipped into or painted with a slurry of the glazing material. If the faience objects were being glazed by the efflorescence method, all of the glazing material would have been mixed with the core material, as was carried out in this research.

The mixing process would have taken a considerable amount of time, as crushing and grinding quartz (and most likely sand too) to a fine powder would have been difficult as both materials are quite hard (quartz is seven on the Mohs hardness scale). If sand was used it might have been ground too, or sieved so it had small particle sizes, as sand grains vary. The other ingredients such as plant ash, natron, and lime would have been easy to crush in comparison.

The second proposed method of mixing the ingredients for faience could be termed pre-mixed, as several of the raw ingredients would be mixed together in the act of creating another artefact. Stocks (1989) can be credited with spearheading this idea in his experimental research. He determined that the dust produced by stone working with a cylindrical copper drill bit would have been an excellent by-product from which to make faience. It would already contain the silica and copper, mixed together as very fine particles, so the only addition necessary would be an alkali (Stocks 1989: 528). This would have saved faience craftsmen a considerable amount of time crushing and grinding quartz and sand to a fine particle size. However, this raises questions as to how this dust would have been collected, such as; would the dust be gathered at a centralised point? Would there have been a lubricant used to aid the drilling, and if so, how was this slurry collected? There are many questions regarding this proposed method of faience production. Ancient Egyptians are known for their organisational skills, and could have controlled the distribution of a by-product such as this dust, but would they have considered it to be an efficient approach? Or could this have been more of a small-scale practice, with a few stone vessel makers gathering the dust and trading the waste product to faience craftsmen?

This is all speculation as there are no records of how the ancient craftsmen produced faience and therefore no way to prove or disprove this theory. Stocks (1997: 181 and 2003: 22) however, was able to create faience using this method of production. He was able to produce a powder of 97.7% granite, 1.1% limestone, and 1.2% copper, and then he added some sodium bicarbonate and fired the material. He then concluded that the experimental faience produced was similar to the archaeological samples (Stocks 1997: 181).

Regardless of the method used, all of the ingredients would then be combined, and the common conception is that water was then added to form the faience paste. The quantity used was important - too much would result in slumping and the material would not hold its shape, and too little would cause cracking during forming (Noble 1969: 436). The correct degree of moisture had to be maintained. However, there is no proof that water was the only liquid used to moisten the paste.

A test was conducted using vinegar instead, as it is a mild natural acid, which could evaporate quickly and possibly improve the working properties in the production of faience. Using vinegar actually did improve the workability of the faience paste (Batch 33 and 34 Appendix J). It foamed slightly when added to the faience paste, and during forming the beads never slumped or needed more liquid. There seemed to be the perfect amount of liquid. During drying the faience seemed to form the efflorescence salts quickly. However, after firing the faience instead of being blue in colour was purplish, most likely due to an unexpected chemical reaction with the vinegar.

7.3.2.1 PARTICLE SIZE AND THE ARABIC GUM CONUNDRUM

The size of particles used in the mixing process developed as an issue during the experimental research. The first ten batches lost their structural integrity and returned to sand a month after firing. It was determined that these samples were not mixed well enough. This led to a very interesting question regarding particle size, and whether or not faience material required the addition of Arabic gum or ball clay to improve its workability, and to maintain structural integrity.

The vast majority of experimental archaeology conducted on faience has included some type of binding agent – either Arabic gum or ball clay – to improve the workability of the faience material (Andrews and Van Dijk 2006: 99, Eccleston 2008: 33, Tite *et al.* 2007: 1570). Yet there is no evidence that this was common practice for ancient faience craftsmen, as there is no literary or scientific evidence for these additions, and if an organic component was used, it probably burned away during firing. However, if clay was used it should be apparent in the chemical composition of the artefact (Lucas 1933: 657). No clay was present in any of the archaeological samples studied for this research, and there was no indication that Arabic gum was added.

The addition of Arabic gum or clay probably stemmed from the expectation that faience should be easily workable, like ceramic clay. However, faience is an entirely different material type, and our modern expectations of workability may never have occurred to ancient craftsmen. Faience could have been accepted for what it was, as the tradition of working faience passed from generation to generation, and they were accustomed to its working properties. Previous researchers lacked the generations of expertise, and consequently found it difficult to work the material, so they attempted to make it easier to manipulate with these additions. Therefore, an attempt was made as part of this experimental work to use

only those major components known from archaeological samples, or to substitute them with close modern equivalents. As such, no clay or Arabic gum was used.

It was proposed that, if the particle size was small enough, the faience would not need Arabic gum or clay to keep it together. The small particle size would improve the working properties, improve the structural integrity of the faience body, and avoid a rough granular structure on the surface, thereby improving the glaze (Miller 2007: 138). This meant that even sand would need to be ground and crushed to produce small particle sizes (La Delfa *et al.* 2008: e115). If this was the case, then the identification of the silica content based on angular particle sizes alone was no longer appropriate, because the sand particles would have become angular from crushing (Tite and Shortland 2008: 37-38).

In order to determine the appropriate particle size for the experimental samples, an assemblage from each time period and museum was randomly selected for sampling. Ten beads from each of these assemblages were then inspected using the SEM images already obtained (Profile 1 and 2 for each bead in BEI, Appendix O). The largest particles in the matrix were measured to determine the maximum particle size within the archaeological samples. These were then averaged for all of the archaeological faience beads sampled and the range was found to be between 42 and 248 microns (Appendix P). To obtain such small particle sizes the silica sources were subjected to mortar and pestle grinding, and sieving. This process was very time consuming, and indicated that either Stocks (1986) theory regarding the collecting of dust was accurate, or Egyptians had enough labour power and time to dedicate to grinding silica. It also seemed that sand would be the better choice of silica source; if this were the case, as it would require less time to grind than quartz pebbles (Tite and Shortland 2008: 203). A mechanical crusher in the Earth and Ocean Sciences Department at the University of Liverpool was then utilised to speed up this process, so that crushing took seconds rather than days.

Batches 11 to 44 were made with powdered silica from the mechanical crusher. The same particle size measurement procedure that was conducted on the archaeological samples was then conducted on the experimental samples (Appendix O for the SEM images and Appendix P for the size measurements). The initial batches were larger in particle size with an average size of 358 microns. It was determined that the crushing device should be used for a longer period of time (15 seconds) for the later batches, resulting in particles ranging between 77-214 microns, which is similar to the range found in the archaeological samples. The smaller particle sizes did improve the workability of the faience paste. It was much

easier to form beads, and the colour and glaze were vastly improved and homogeneous. The experimental faience batches were harder, and have successfully maintained their structural integrity. No binding agent or clay additive was necessary to produce these beads, due to the smaller particle size.

7.3.3 Forming and Piercing

As stated in Chapter 2, there were two common ways to form faience beads: moulding and modelling. The modelling method was the only method used for this experimental work, as it was the easiest way to produce beads without having to make or apply for access to moulds. The modelling method produced simple forms, which were perfectly suitable for this experimental work (Noble 1969: 437). There were also two ways to produce the perforation in a bead: by piercing the bead or by inserting a reed during the forming process. Both methods were attempted as part of this research, in order to check their effects on the beads, and to discover which method was most likely to have been used.

Two types of beads were made for this experimental work: ball beads and cylindrical beads. The ball beads were produced by rolling faience paste in the palm of the hand, which was much easier after the raw material was mechanically crushed. Once the ball was formed it was pierced with a needle to form the perforation. The cylindrical beads were formed by rolling the faience paste around a reed. It was then cut into sections or left whole. Both methods of perforation were attempted on both types of beads. However, it was very difficult to form a ball bead with the reed method, as the reed gets in the way of rolling the bead. Also it was very difficult to pierce the cylindrical bead because the needle would sometimes pierce the bead half way through. Therefore the ball beads were all pierced and the cylindrical beads were all produced over reeds.

Figure 7.5: Experimental cylinder and ball bead perforations.

7.3.4 Drying and Firing

Once the beads were formed they were then dried on glass trays. Several different methods of drying the beads were attempted, in order to replicate Egypt's

weather. The beads were dried in desiccators to absorb all of the moisture, ovens set to 40^{o} C to mimic Egypt's dry heat, under heat lamps to replicate the suns heat, and at room temperature. These were all attempted to produce soluble glazing salts that effloresce to the surface of the beads (Tite *et al.* 2009: 372). The beads were rotated to ensure that the air flowed to all sides of the beads so the salts would form. All methods seemed to produce the same results; the salts did form, but they did so unevenly, with no observable pattern. Another interesting phenomenon was that the beads pierced by a reed seemed to form glazing salts faster than non-reed beads. This could be because the reeds absorbed the moisture from the inside of the bead, allowing the surface to dry more quickly.

After the beads were dried they were then fired in an oxidizing atmosphere at temperatures ranging from 800-1050^{o} C and from 45 minutes to six hours. The range of temperatures and durations were varied to see first how well the glaze was formed, as the depth of the glaze penetration into the body of the faience object depends on the firing time and temperature (Vandiver 1998: 127). The temperature and duration were later used for the Mohs experiment discussed in Section 7.3.4.1.

The firing was accomplished in a modern furnace that can maintain a temperature of 1200^{o} C. The faience samples were put in the furnace, and the temperature was gradually increased over an hour, before maintaining that temperature for the desired length of time. When the firing was complete, the furnace was left to cool off until around 200^{o}, and the samples were then removed and left to cool at room temperature.

The results from altering the firing temperature did not vary as much as predicted. There was only one case of a glassy glaze being achieved (Batch 15), the others all produced a matt glaze. The copper did oxidise and the vast majority of the beads changed colour. The reeds used for the cylindrical beads burned away and left very little evidence of their presence. The only indicator that the bead once contained a reed was at the very end of some of the samples. There was a little lip of faience material, hardened where it once rested on the now vanished reed. Apart from this, neither set of beads indicated clearly whether they had been pierced or reed perforated.

7.3.4.1 MOHS HARDNESS

During the pilot study (Hammerle 2008) it was found that the hardness of beads from the Middle Kingdom to the New Kingdom varied in a different way than had been suggested by previous research. Andrews and Van Dijk (2006: 100), Boyce (1989) and Vandiver (1982) state that New Kingdom faience built on the

development of previous periods, and with the aid of glass technology, created a stronger faience with greater hardness, more vitreous structures, and new colours. However, when analysing the samples for this research, the Middle Kingdom beads seemed to maintain a higher hardness similar to the New Kingdom number, according to the Mohs Hardness Test (discussed in depth in Chapter 4, Section 4.3.4). However, the range of hardness in all time periods seemed to vary more than was expected. Middle Kingdom, Second Intermediate Period, and New Kingdom beads had a very wide range of hardness levels, from quite soft to very hard. These numbers ranged from 2/1 to 8/9 for the Middle Kingdom, 5/3 and 6/6 for the Second Intermediate Period, and 3/3 to 7/7 for the New Kingdom (the core hardness being the first number and the glaze being the second number) (Appendix A).

To test what caused such variation in hardness, experimental samples were subjected to a variety of different temperatures and firing times. In order to attribute the variation to these two variables and no others, only two batches were utilised for this experiment: Batches 42 and 43. These two batches were selected because the only difference between them was the copper colourant: metallic copper for Batch 42 and cupric oxide for Batch 43. The beads from these batches were then fired at temperatures from 800^{o} to 1050^{o} C and from one to six hours. The fired beads were then cut in half with a diamond saw, and the core and glaze of each half-bead were subjected to the Mohs scratch test. The results varied more than was expected, with no consistent trend other than that the higher firing temperature (1050^{o} C) produced the highest hardness numbers for both batches (Tables 7.1 and 7.2).

Hours/ Temp	**1**	**2**	**3**	**4**	**5**	**6**
800 ^{0}C	3/4	3/5	3/4	3/4	4/5	4/6
850 ^{0}C	3/4	3/5	3/4	3/4	3/5	3/4
900 ^{0}C	3/4	3/4	3/4	3/4	3/4	3/4
950 ^{0}C	4/5	4/5	4/5	4/5	4/5	5/5
1000 ^{0}C	3/3	3/4	3/4	4/4	5/4	4/4
1050 ^{0}C	4/5	5/6	5/6	5/6	5/6	5/6

Table 7.1: Batch 42 Mohs hardness results.

Hours/ Temp	1	2	3	4	5	6
800 ^{0}C	3/5	3/4	3/4	3/4	3/4	3/4
850 ^{0}C	3/4	3/4	3/4	3/5	3/4	4/5
900 ^{0}C	3/4	3/4	3/4	4/4	4/4	4/4
950 ^{0}C	3/4	3/4	3/3	3/3	3/4	3/4
1000 ^{0}C	3/3	3/4	3/4	3/4	4/4	4/4
1050 ^{0}C	4/4	4/4	4/4	5/6	5/6	5/6

Table 7.2: Batch 43 Mohs hardness results.

Four samples were then selected for SEM-EDS analysis from these two batches, to determine if there was any variation in the microstructure of the faience beads, based on the temperatures reached by the samples. Only these four samples were selected, because the other samples were similar in either colour or hardness. Therefore, the samples fired at the highest temperature (1050^o C) and at the lowest temperature (800^o C) were selected to show the range of temperatures and any structural variation that might occur. All four samples were from the groups that had been fired for five hours, in order to provide enough time for the interparticle glass to fully form in the samples. It is the interparticle glass that can provide the strength and hardness in the faience, as it binds the silica particles together (Andrews and Van Dijk 2006: 100).

The results from the SEM image analysis shows that the samples fired at 800^o C lack interparticle glass, whilst the samples at 1050^o C do have interparticle glass (although very little in some areas) (Appendix L). Another interesting phenomenon is that the images show no glaze development for any of the beads at either temperature. This is very interesting, and is something that has been noticed in a few other experimental samples, but is so far unexplained. There is no reason that the glaze should not have formed; the research aim in the future is to tackle this question.

As for the comparison of the Mohs hardness results of the experimental samples with the archaeological ones, there is not much to be said. There do not appear to be any trends that explain the hardness variation in either of the sample groups. The only positive result from this experiment is that higher firing temperatures produce harder faience. The harder archaeological samples could, therefore, have been fired at higher temperatures, as suggested by the increase in interparticle glass.

7.3.4.2 IRON PARTICLES

During the SEM-EDS analysis of the archaeological beads from the Middle and New Kingdom, several beads were found to have a particular trait when it came to the distribution of iron within the faience material. Metallic iron prills are evident in 23 Middle Kingdom beads and nine New Kingdom beads. There were no iron prills in any of the Second Intermediate Period beads. As part of the experimental faience work, an attempt was made to replicate the presence of these prills. This was done by using raw material sources with high iron contents, such as the Ainsdale sand for silica and the Chalcopyrite mineral for iron and copper. The batches with the highest iron levels corresponded with these two raw material sources, so Batch 17 had Ainsdale wet sand as its silica source, and Batch 36 had chalcopyrite as its colourant source. The EDS results for both of these samples had high iron levels consistent with archaeological examples (Appendix M). These beads were fired in both an oxidising and reducing atmosphere. However, it was very difficult to obtain a reliable reducing atmosphere. The beads were placed in a crucible covered in silica sand, with another crucible as a lid on top to limit the airflow around the sample. This was done to see if the reducing atmosphere alone caused the iron prills, or if they were due to a change in chemical composition.

The SEM image results were inconclusive as to what caused the iron prills. As expected, Batch 17 had iron at about 2%, and iron prills were present in the bead. However, Batch 36, made with chalcopyrite, had iron (averaged 1.82%) with no iron prills apparent (Appendix L). Therefore, iron prills were not caused by the presence of iron per se. Another oddity is that the iron prills were present in several other samples that should not have had high iron, and were not subjected to a reducing atmosphere (Batches 15, 19, and 26). These beads would have had iron as an impurity in the sand only, and were fired in a normal oxidising atmosphere. This leads to the interpretation that the iron prills are not necessarily created from a reducing atmosphere, or as part of a high iron chemical composition. It is possibly due to some internal mechanics of the faience material, during firing, causes the prills to form from an iron impurity within the sand no matter what the abundance. As iron has a higher melting temperature and is more chemically active than copper (Schmidt and Childs 1995), it might not migrate throughout the faience body as copper does and instead turns into prills within the silica matrix. This will need to be studied more with further experimental work.

7.3.5 Glazing

As discussed earlier, the glazing method would have been selected before the mixing process. This section discusses the glazing methods utilised in the production of the experimental beads. Efflorescence was the main glazing method utilised (Batches 1-43) as it was determined to be one of the easiest methods to replicate, because all of the raw materials were mixed together (Tite *et al*. 1983: 18). One of the key characteristics regarding efflorescence is that there is extensive interparticle glass throughout the faience bead. However, only a few of the experimental samples showed signs of interparticle glass (Appendix L, Batch 19, 26, 39, 41, 42 (1050^0 C), and 43 (1050^0 C). Considering that the majority of the batches were produced using efflorescence, these were rather poor results. There could have been a number of reasons for this, for example, the recipe was incorrect and more sodium should have been added, the firing temperature was too low, and/or the firing time should have been longer. The other issue is that there was no true glaze on the surface of any of the beads. This could be due to the same reason why there is very little interparticle glass.

Due to these results, an attempt was made at cementation glazing, in order to produce a proper glassy glaze (Batch 44). The core material was pure silica crushed to a fine particle size and formed into a ball. This bead was then allowed to dry and covered by the glazing powder, which consisted of sodium, calcium, silica, and copper (Appendix J). The bead was then covered with a crucible to replicate a saggar. After firing the hardened crust of glazing salts was cracked-open to expose the blue bead within. The bead was then analysed with SEM-EDS to determine if the glaze had formed and if the bead matched the expected results for cementation glazing (a core of silica, interparticle glass, and glaze). The core was perfect and there was very little interparticle glass. However, there was still no glaze present. The colour and appearance was similar to that of the archaeological samples, but the SEM images indicated that there was no glaze (Appendix L). This could have been caused by the firing temperature being too low, or there not being enough alkali to lower the firing temperature, or because the batch should have been fired longer. As Vandiver (1982: 169) states, the cementation glazing method requires more time for the glazing salts to react with the core. This experiment will be attempted again in the near future for a longer length of time, to see if this increases the glaze presence.

Another experiment was conducted, based on previous research by Vandiver (1998) who states that Egyptians used several different glazing methods

on individual faience objects to obtain the desired glaze appearance. This means that if the original glazing method did not work, then they would glaze the object again by the same method or another method entirely. A bead from Batch 42 and one from Batch 43 were selected to attempt double-glazing. The beads were originally prepared for efflorescence, as all the glazing material is mixed in with the core material. Then they were buried in glazing salts and covered with a crucible. After firing the beads were removed from the hardened crust and prepared for SEM-EDS analysis. During the sample preparation it was observed that the beads were blue all the way through, although there was still a distinction between the core and the glazed area, with the glaze being a brighter blue. The results of this glazing attempt were similar to all the other glazing methods, in that the SEM-EDS images had a similar appearance to all of the other beads, with just a little more interparticle glass. Therefore, it is very difficult to determine whether the beads were glazed once or twice with the SEM-EDS analysis (Appendix L). However, the appearance of the beads using the naked eye does indicate double-glazing due to the two distinctly different layers (core and glaze). The glazing method still needs to be researched further, because even though these beads were glazed twice, they still did not have a distinctive glaze layer in the SEM images. More research needs to be conducted to determine why this was the case.

7.4 Experimental Analytical Methods

The second set of experiments completed for this research consisted of analytical methods that have been used for several decades by the Earth Sciences. They have never been used on faience material, and have only recently been applied in the field of archaeology. These analytical methods were employed in order to better understand the silica in faience that comprises 92-99% of the beads composition. Crystallography (CL) was undertaken to better understand the silica source of the archaeological samples, and electron backscatter diffraction (EBSD) was completed to determine the firing temperatures reached in faience's production, based on the silica grains' crystal orientation. This section will present the analytical methods and results of two bead samples from the Middle and New Kingdom.

7.4.1 Crystallography

One of the main objectives of this research is establishing the silica source of the archaeological samples. There are two methods routinely used by faience researchers for determining the source of silica, be it crushed quartz or sand. The first method is to determine by microscope or SEM whether the particles are angular

or rounded. If the particles are rounded then the silica source is sand, because they have been weathered and smoothed. If the particles are angular then crushed quartz is the main silica source, as they had to be ground down. However, as stated in Section 7.3.2 this is no longer a valid method, because even sand would have needed to be crushed for faience production. The other method for determining the silica source is by the presence of impurities, usually detected by chemical analysis of some sort, such as EDS. If titanium, iron, and aluminium are present then they indicate that sand was the source, because natural forces, such as wind, mix in the impurities with the sand. However, if there were no impurities then the source is quartz, as it would have been used in pure crystal form. It became apparent during this research that both impurities and angular particles were present, meaning either both sources were used in a mixture, or that these methods are simply not adequate for determining the silica source. This is why crystallography was undertaken, in the hope that the silica source could be more scientifically determined by a tried and tested analytical method (in the Earth Sciences) rather than by previous investigative techniques and approaches.

7.4.1.1 HOW CL WORKS

CL is a qualitative analytical method commonly used by the Earth Sciences for determining mineral crystal structures. In determining the structures, vital information can be obtained, such as the possible source of the mineral, intergrain impurities, and how the crystal was formed and deformed over time. The sample preparation is the same as for SEM (see Chapter 4) and was completed in the University of Liverpool Department of Archaeology, Classics, and Egyptology (ACE) laboratory. This process required the samples to be cut, mounted in resin, polished to ¼ micron, and a very light carbon coat applied, so as not to affect the topography and complicate the crystal lattices.

Once the sample was prepared the CL was collected on a Philips XL30 SEM at the University of Liverpool Earth and Ocean Science Department (EOS) (the same facility was used for the EBSD analysis discussed later). The sample was then studied and large particles were randomly selected for potential CL. Once a particularly informative crystal was identified, the CL was then conducted to collect the data. The sample shows up in varying shades of grey, which depict the grain boundaries and edge effects that are inspected during the data collection. After the data are collected the images are then processed via the Channel 5 software system.

7.4.1.2 RESULTS BEAD 2383-1

Bead 2383-1 is a Middle Kingdom bead that was inspected in order to establish whether the silica source was sand or crushed quartz. The initial picture (Figure 7.6) is an image in SEI. This grain was selected from others in the core material due to its size and its angular attributes. If the previous visual investigative processes were right, then this grain would be from a crushed quartz source. However, upon viewing the CL data images the particle actually shows up with intergrain impurities representing themselves in different shades of grey (Figure 7.7). The edge effect on this same particle indicates that it was not crushed but actually ground down naturally, as shown by the darker edges of the image. This darker edge could be indicative of the grains bearing the original structure of its mother sandstone. Due to the impurities and the edge effect, this grain was determined to be sand. However, the other particles around the one sampled have the edge effects of particles crushed during production and therefore could be quartz or coarser types of sand. Therefore, this method is highly selective and could be biased with the minority attempting to represent the majority of grains present.

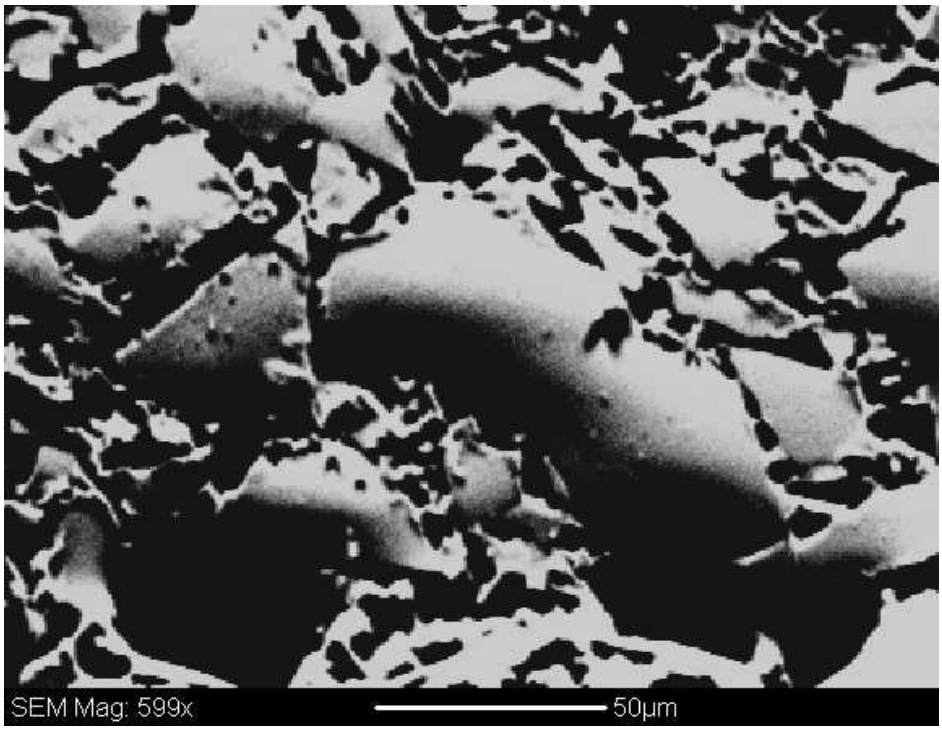


Figure 7.6: SEI of Bead 2383-1 core layer before CL analysis.

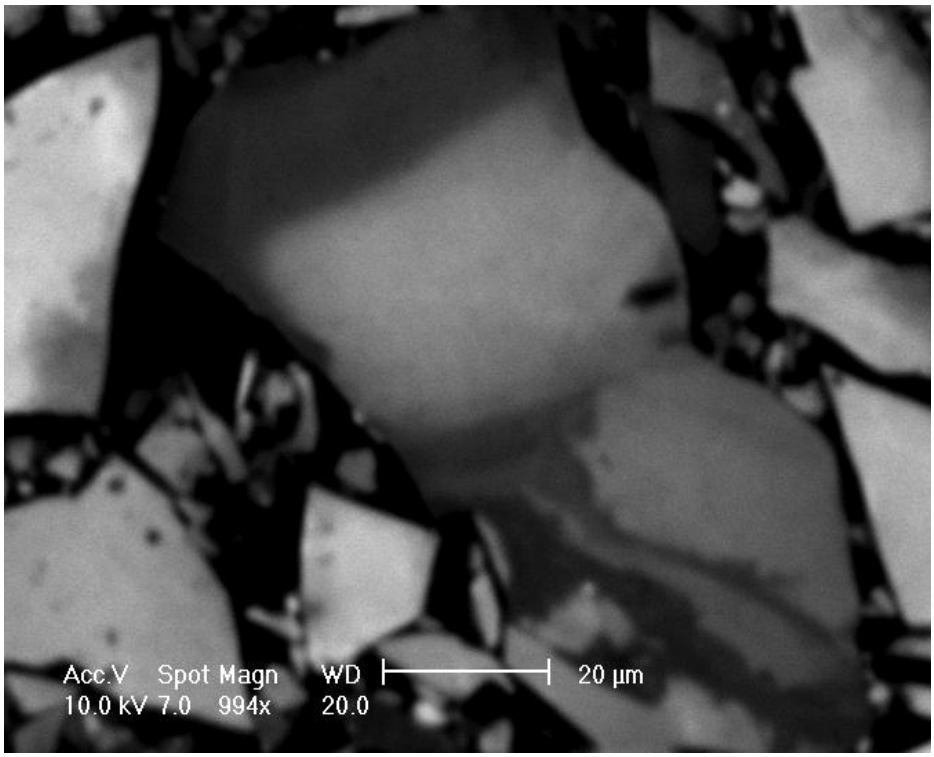


Figure 7.7: CL of Bead 2383-1, close up of sand particle, showing the variation within one particle.

7.4.2 Electron Backscatter Diffraction

EBSD is also referred to as electron backscatter patterns (EBSP) and backscatter Kikuchi diffraction, named after the man who discovered the patterns. However, this research will use the terminology set out by Prior *et al.* (1999), which states EBSD will be used in reference to the technique, and EBSP will be used to refer to the individual diffraction patterns. These patterns are used for measuring the absolute orientation of known materials, and for measuring elastic strain. EBSD provides the full crystallographic orientation of any point within a sample. However, it still needs to be run with CL to record the crystal information, because none of the CL information acquired during EBSD is retained - it is only utilised to determine the EBSP.

During this research, EBSD was applied for the first time as a new avenue of research for the study of vitreous materials, and is relatively new to the field of archaeology. Peruzzo *et al.* (2011: 178) published one of the first studies where EBSD analysis was used on archaeological samples. The authors used EBSD to determine the mineralogy of the crystals present in ancient coloured glass and ceramics. EBSD has been widely used in the Earth Sciences since the 1980s, however it was not until 1994 when the first publication of data using automated indexing and orientation mapping appeared that the method became more popular.

Before this occurred the issue of mis-indexing was a huge problem, and was not rectified until the approach of using a solid state detector, either tilted or attached to the camera, was adopted in order to provide a qualitative orientation contrast Image (OCI), which would limit the effect (Prior *et al.* 2009: 346). EBSD is now fully automated, provides reproducible data, and is fast (Mariani *et al.* in press: 8).

EBSD was chosen for analysis of the silica content within the faience materials, in order to determine the viability of the method for determining silica sources, and possibly the firing temperatures reached by Egyptian faience manufacturers. This was accomplished by analysing two archaeological samples to determine their mineral crystal orientation, identify the substance based on its crystal lattice, and the strain on the particles/crystals.

7.4.2.1 QUARTZ

EBSD has proved to be very successful when it comes to studying quartz based materials. In fact, there is a dominance of quartz studies in the EBSD literature due to it being one of the most common minerals in the Earth's upper crust. Previous studies, such as that of Wheeler *et al.* (2001: 114) on quartz have investigated the deformation of quartzite under variable conditions. Other detailed EBSD microstructural studies have the potential to identify phases of activity, such as Kruhl (1996) who distinguished sub grains α-quartz and β-quartz (which will be discussed later).

EBSD has achieved excellent results for calcite and quartz indexing, providing full automation and results that cannot be obtained using the optical microscope (Mariani *et al.* in press: 12). Due to this realisation the University of Liverpool Earth and Ocean Science Department has a custom-designed sample stage for the CamScan x500 FEG-SEM (one of only two in the world), which can combine EBSD analysis, EDS and SEM imaging (Mariani *et al*. in press: 18).

7.4.2.2 HOW EBSD WORKS

EBSD is accomplished on an SEM and can be used to measure the full crystallographic orientation of any mineral sample by analysing the selected area for patterns, (Prior *et al.* 2009: 346). The electron beam is set up as an omni-directional source for electrons (Mariani *et al.* in press: 8). The SEM's backscattered electrons are diffracted simultaneously on all lattice planes, and the diffraction pattern will then be imaged on to a forscattered positioned (in front of the sample) phosphor screen, generating the Kikuchi patterns (Prior *et al.* 1999: 1741). Different crystals generate

different patterns (Mariani *et al.* in press: 7). This pattern is then indexed against a known material, and the crystallographic orientation is determined.

7.4.2.3 SAMPLE PREPARATION

As stated previously, the sample preparation is the same as SEM and CL analysis. In order to obtain quantitative analysis, the specimen surface needs to be perfectly flat, a stable beam current is needed, and current measurement completed against analytical standards (Peruzzo *et al.* 2011: 184). The surface of interest must be very smooth to avoid shadows and therefore mechanical and chemical (Syton) polishing is necessary to provide a pristine lattice, which extends to within a few nanometers of the specimen surface (Mariani *et al.* in press: 9). Samples must be kept very clean, as any dust particles will cast shadows, affecting the imaging abilities of the EBSD, so the sample is dusted off before analysis (Prior *et al.* 1999: 1746).

7.4.2.4 MACHINE SET UP

The SEM set up is slightly different from when it is utilised for basic EDS analysis or SEI and BSE imaging. The chamber has to be at an incident level of 70 degrees in order to ensure that the detector is as physically close to the sample as possible. This aids in minimizing the errors that can occur due to shadowing and helps the resolution (Prior *et al.* 1999: 1749). In the field emission SEM, the resolution of EBSD is <1µm and sometimes lower if the specimen is tilted to 70 and the accelerating voltage is 20 KV (Mariani *et al.* in press: 9). Another factor is the spot size, which can affect the quality of the EBSP. A large spot size aids in obtaining a clear EBSP, but this can reduce the resolution and must be maintained at around 6 or 6.5 to be the perfect medium. The working distance should be maintained at about 25 mm to ensure reliable quantitative results.

7.4.2.5 SOFTWARE

Since the EBSD method used for analysing quartz is fully automated, the software is very important and includes several different programs with specific functions: Flamenco for acquisition of information, Tango for the map processing (where the background signal can be corrected), Mambo is the Statigraphic projection program, and Salsa is the orientation distribution function (ODF). This software enables data to be collected and processed as quickly as 600 data points per second (Mariani *et al.* in press: 11).

However, there are a few problems that need to be addressed with this analytical method. The software needs to be carefully used in order to minimize the levels of miss-indexing and non-indexing, whilst being able to reconstruct the sample microstructure with enough detail for analysis (Prior *et al*. 2009: 349).

7.4.2.6 RESULTS

The results presented here are for two beads that were analysed using SEM-EDS, and EBSD concurrently. One bead (Bead 2383-1) was from the Middle Kingdom and the other bead (Bead 2377-5) was from the New Kingdom assemblages. They were picked at random since they were the most prepared samples at the time that this research was undertaken. Both beads had a step size of 1µm and were run overnight (over seventeen hours for each sample).

The EDS coupled with the SEM provided an opportunity to complete elemental mapping simultaneously with the EBSD, and several observations were made. This method helps to determine if the elements entered the faience mixture by accident or on purpose, depending on how evenly or randomly distributed they appear to be. For the most part faience will be random in the elemental distribution, as the raw materials are all mixed together, but interestingly this method shows the traces of impurities within the silica grains, such as aluminium and iron (Figure 7.8, 7.9, and 7.10). These images from the Middle Kingdom bead match those from the New Kingdom one (Figure 7.11, 7.12, and 7.13) in that both would lead to the conclusion that sand is the source for silica due to the presence of impurities within the silica particles, i.e. aluminium and iron.

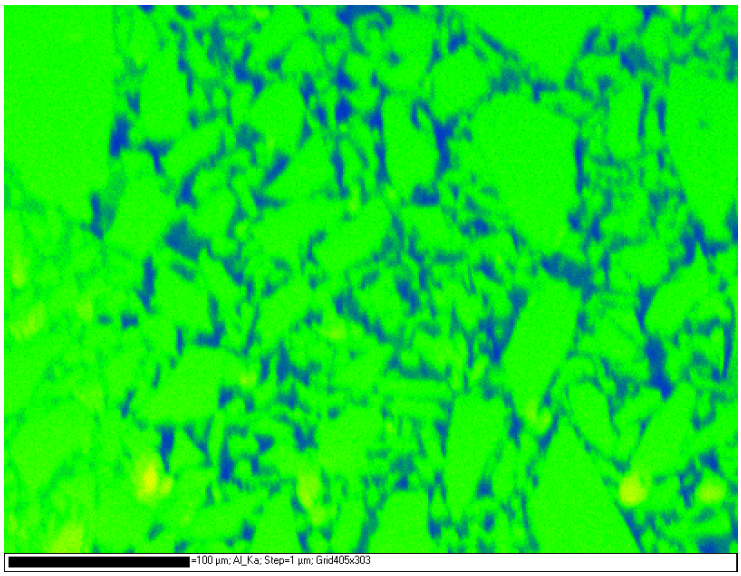


Figure 7.8: Bead 2383-1 aluminium (green) present in the silica particles.

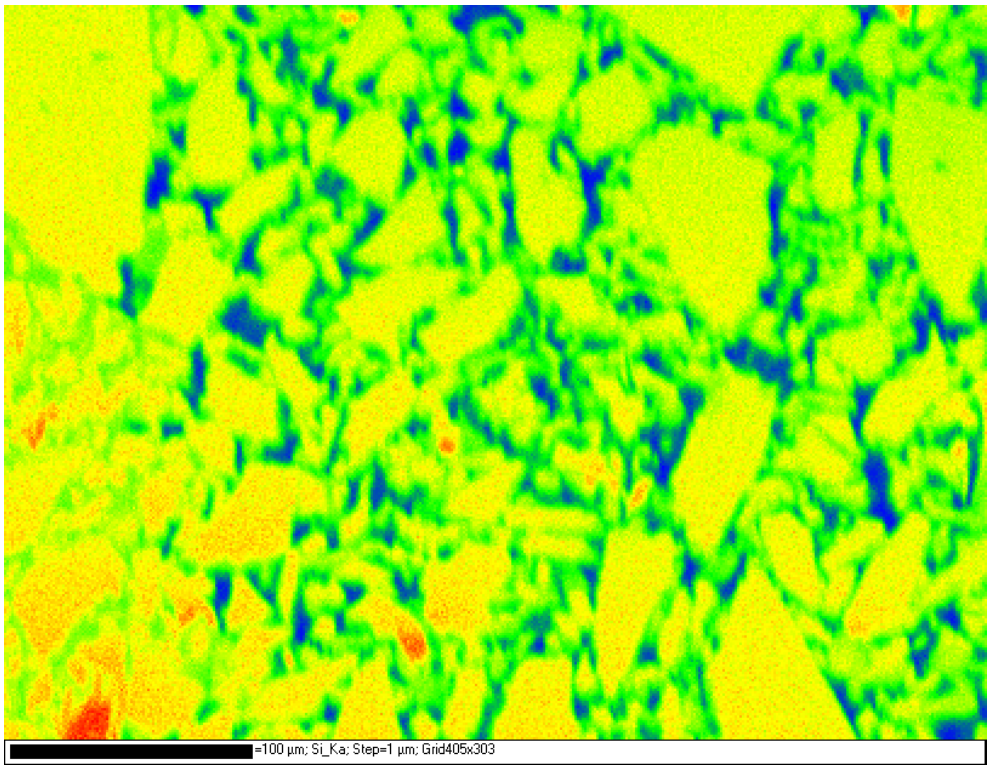


Figure 7.9: Bead 2383-1 silica (presented as yellow).

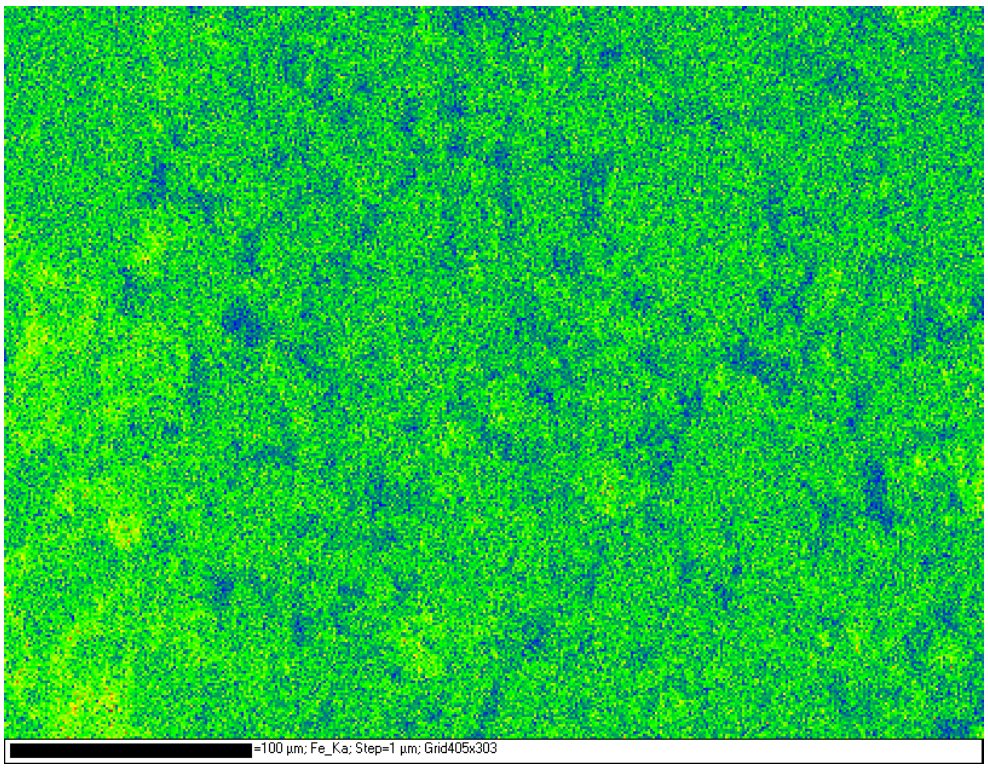


Figure 7.10: Bead 2383-1 iron elemental map depicted in green and spread throughout the silica particles.

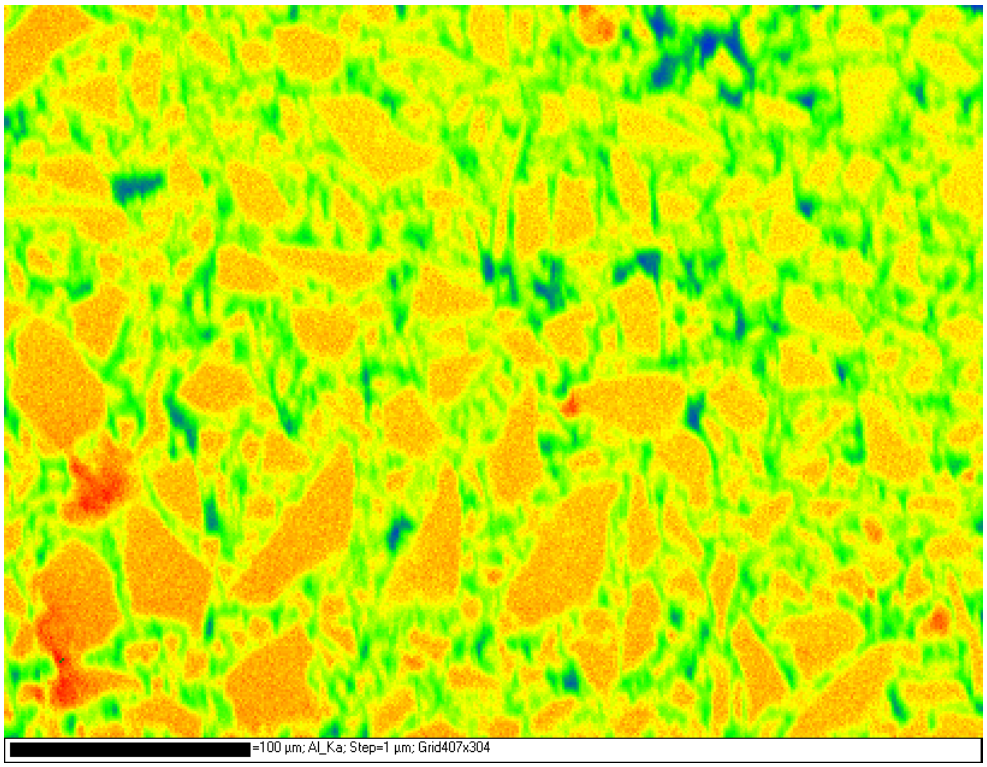


Figure 7.11: Bead 2377-5 aluminium apparent in the silica particles (presented as yellow).

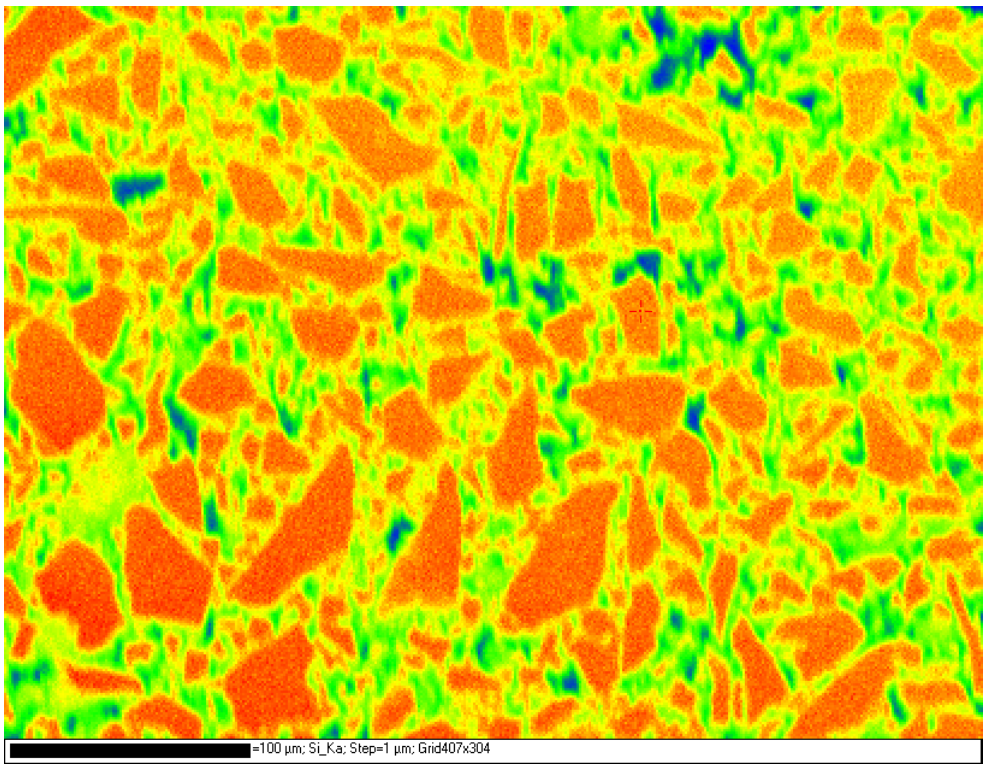


Figure 7.12: Bead 2377-5 silica elemental map. The silica particles are bright orange.

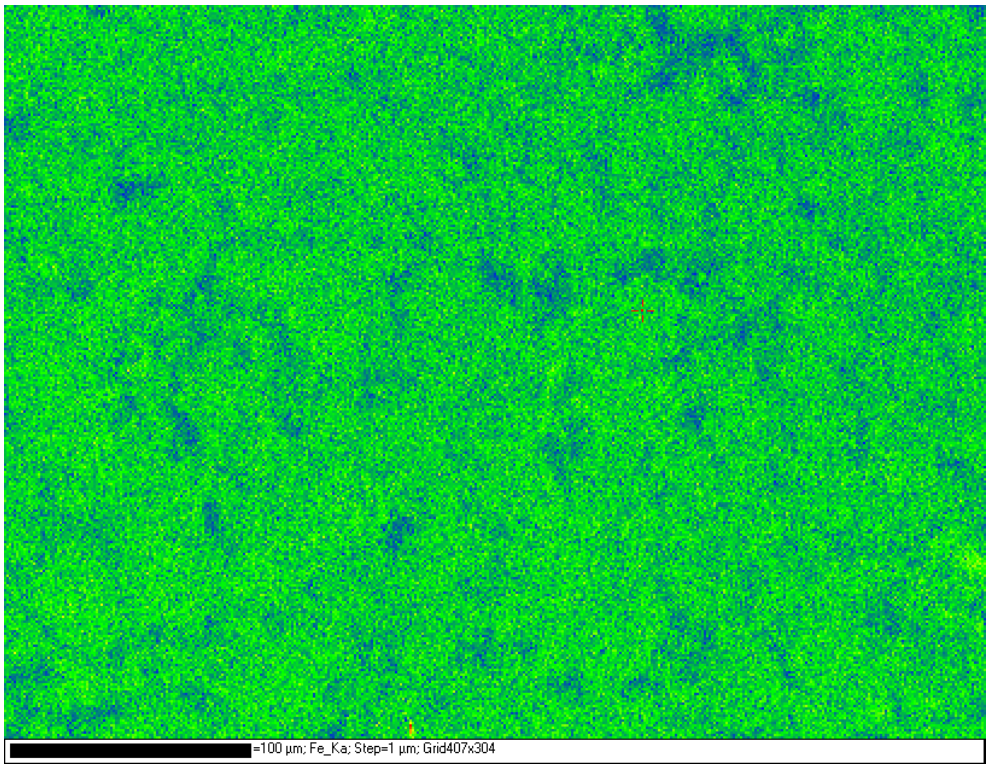


Figure 7.13: Bead 2377-5 iron elemental map showing the iron is throughout the silica particles.

A note should be made about the intensity of colour in these images. This does not indicate an abundance of the element in this location. The colouring is due to the angle of the sample, since the intensity starts in the bottom left hand corner. However, this does not diminish the value of the image itself as it still represents the distribution of the elements.

As for the EBSD results, the Euler angle maps (Figure 7.14 and 7.15) hold the vast majority of information, as each colour is based on the angle and orientation of each crystal within the sample area. Several crystals can have multiple colours, meaning multiple orientations, which are referred to as Dauphine Twins. These twins occur on a single grain of silica with two colours, and usually at each end of the grain. This is known as techtonites, when a single parent grain goes through mechanical twinning due to firing temperatures (Wheeler *et al*. 2001: 114). These twins are common in quartz and usually represent the α-quartz to β-quartz inversion (transformation), which takes place at temperatures over 573^{o} C (Prior *et al*. 1999: 1750, Van Tendeloo et al. 1976: 728). Therefore, these beads were fired at temperatures exceeding 573^{o} C, which is to be expected as faience is fired between 850-1000^{o} C. However, there is the potential of EBSD identifying structural changes

to faience material at higher temperatures though more experimental work needs to be conducted first.

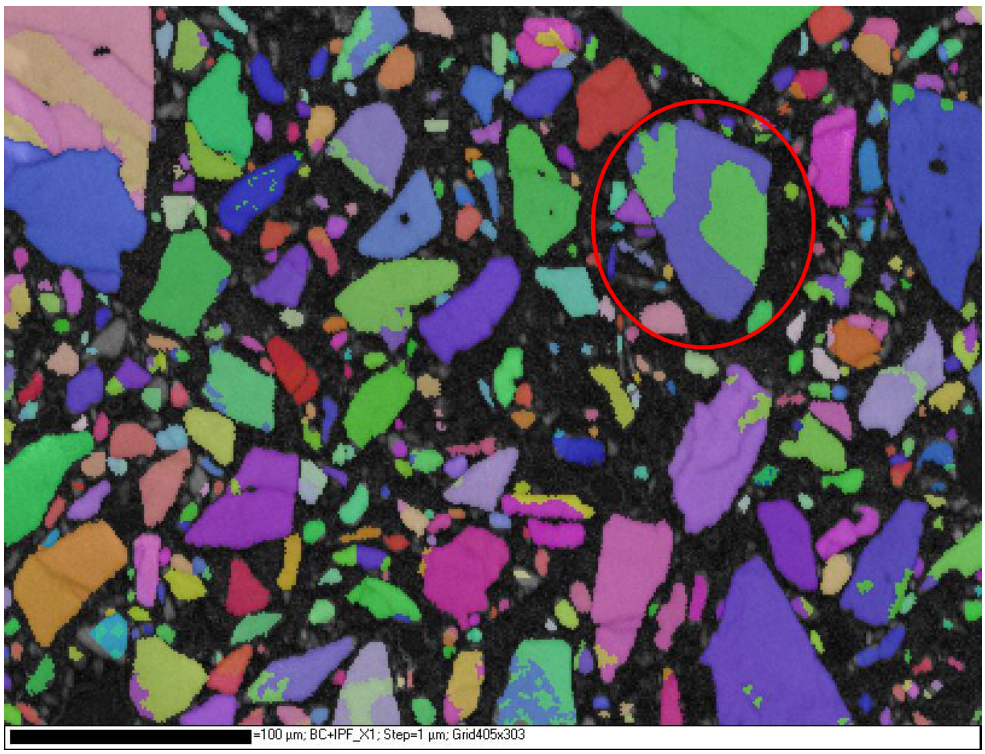


Figure 7.14: Bead 2383-1 EBSD orientation map (the red circle surrounds a dauphine twin particle).

Being able to determine the firing temperatures of the particles within faience is very exciting. More information would be attained from archaeological samples and their firing conditions. However, these results are very tentative and much more work needs to be conducted to test EBSD's potential, to determine if other quartz transitions can be observed during firing. Originally this was planned for this PhD research, and EBSD was going to be conducted on the experimental faience, but due to lack of funding this work was never carried out. It is hoped in the future that such work would be conducted. Since the CAM-SCAN SEM has a hot stage, which means faience would be fired within the SEM while EBSD is being conducted, the crystals' morphology would be observed in action. The experimental samples would then be compared to the archaeological samples, and these results would prove the usefulness of EBSD as a means to discovering the firing temperatures of faience.

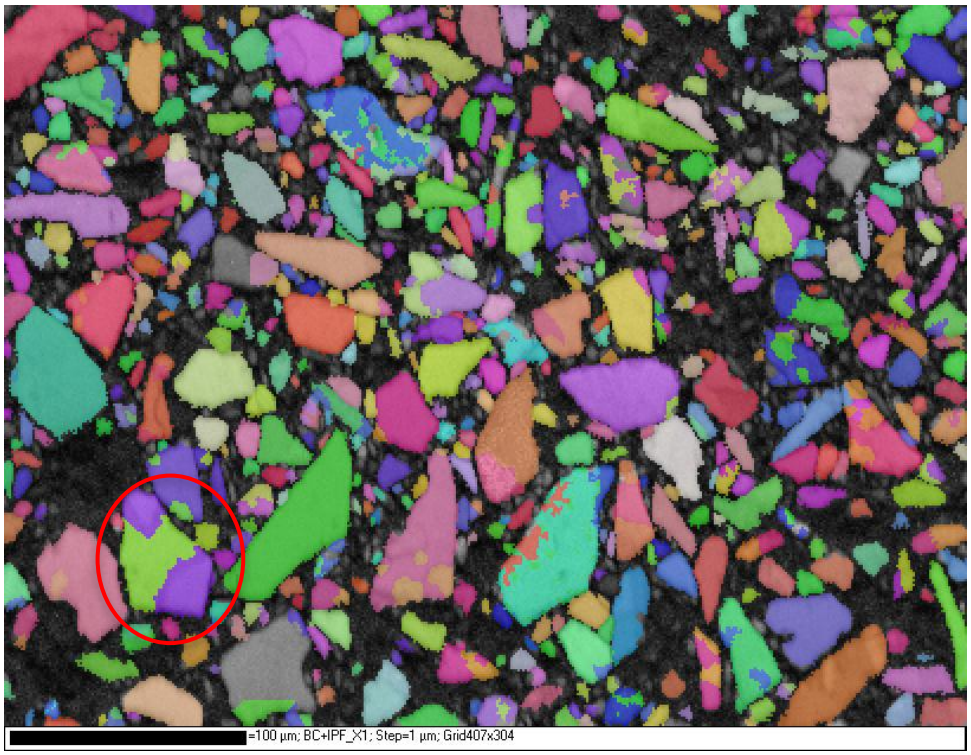


Figure 7.15: Bead 2377-5 EBSD orientation map (the red circle surrounds a dauphine twin particle).

7.5 Discussion and Conclusion

Three questions were outlined at the beginning of this chapter. The first of these regarded the hardness of the faience beads, and whether it was caused by the firing conditions. An attempt to answer this question was made by conducting firing experiments at several different temperatures and for different lengths of time. The result was that higher firing temperatures and longer durations created harder beads. However, any other variations in hardness at the lower temperatures and times vary exponentially. This means that other factors affected hardness, such as the size of the bead, and its individual particle dispersal within its matrix. In other words, the hardness experiment proved inconclusive at explaining why the hardness varies at lower temperatures and duration of firing times. This potentially indicates that, when it comes to faience, tightly controlled firing conditions are not required, and faience could have been made in a bread oven (Eccleston 2008: 33) with little variation in hardness in comparison with faience made in a workshop kiln.

The question regarding the existence of the iron prills and whether they were produced due to firing conditions – i.e. a reduced atmosphere – or compositionally based on high iron content, was ruled to be inconclusive. Beads with minimal iron (as an impurity) and fired in a normal oxidised atmosphere had iron prills, and beads

fired in a reduced atmosphere with high iron had none. Therefore more work needs to be conducted to determine why iron prills form in some beads and not in others.

Several different methods were used to determine if the silica content was sand or quartz pebbles. This included using different silica sources and chemical analysis plus two new analytical methods. The SEM-EDS results point to sand as the sole silica source, based on the impurities present. Attempting to use the angular particles theory is ill advised, as even the sand component would have to be ground down, and there would be sharp fractures in the particles present in faience made from sand.

CL was also used as a method to determine the silica source, and it is a very interesting method, but it is also very subjective. The fact that an unusual particle has to be selected to run the crystallography means that the minority is sampled rather than the majority. This means that a single particle of sand in the matrix of quartz particles could indicate that the faience bead is made of sand, when in fact it is made of quartz. It is suggested that this method be used sparingly and an occasional grain of sand should be expected.

EBSD utilises CL data, however, it is a quantitative technique that requires much more work to determine its full potential for studying faience material. This microstructural analysis has the excellent advantage of being able to be conducted on an SEM at the same time as EBSD, EDS, and BSE. The patterns and EDS data collected from this analysis confirmed that the silica component was sand. Other information obtained included the change in orientation of some of the crystals due to firing, such as the Dauphine Twins and the α-quartz to β-quartz changing (normally at 573^{o} C). In the future it is hoped that this work can be continued to test the viability of using the strain conditions of the faience silica grains to determine the mixing and compaction processes of the particles, and the firing temperatures. It would be good to continue with the experimental work and attempt to replicate the α-quartz to β-quartz change along with the Dauphine Twins.

As for the experimental samples and their raw materials, several choices were favoured. Pure silica sand was determined to be the best choice for glazing, as it produced the finest glaze (Batch 15). However, there is potassium present as an impurity, and this could have aided in producing the glassy glaze. The calcium raw material, although synthetic, replicated the calcium content in the archaeological samples quite well. The quantity of sodium had the opposite effect and did not replicate the levels in the archaeological samples. Its presence when compared to the levels of potassium proved that the archaeological samples have been produced using plant ash as the alkali source. The metallic copper produced the best colour in

terms of similarity to the archaeological samples, whereas the other copper sources produced different colours, some of which have never been seen in faience before.

As for the mixing of the raw materials, it is more likely that the faience was mixed and crushed, as opposed to Stocks' idea of the mixture being a by-product of the stone industry. However, Stocks (1997: 179) has provided evidence that the ancient Egyptian craftsmen were able to produce faience as a by-product by replicating the material. His theory cannot be ruled out, as there is no evidence to contradict him or disprove his theory. However the practicality of collecting the dust is questionable. What is evident is that a fine particle size solves the issue of workability, and that additives such as Arabic gum and clay are not necessary. This contradicts the recipe developed by Binns *et al.* (1932) and the conclusion of Aspinall *et al.* (1972: 27) that particle adhesion was only possible through a binding material being added to improve workability. This could be due to the preconceived notion of what faience workability should be like based on ceramic workability, which Binns *et al.* (1932) had as ceramics.

Despite the best attempts at replicating the glassy glaze during this experimental work, it would not form. There are several reasons for this, including that it could be the result of working in Britain, where the weather and ambient climate are so different from Egypt that the faience material did not dry properly and the salts did not form as they would in Egypt. As Vandiver (1998: 127) put it, "London is like a damp box as opposed to Cairo which provides a dry, high temperature and usually high flow-rate, drafty or windy area." Even more interesting is that Vandiver (1998: 124) had similar results to this experimental work, and her effloresced faience did not produce a good glaze. It would be useful to attempt replication of faience material in Egypt, as Eccleston (2008) did or possibly analyse the replicas from these experiments using analytical methods to determine their accuracy in relation to the archaeological samples.

This research intended to build on the large body of previous experimental work, by not only attempting to produce faience that was similar to the archaeological samples in appearance but in composition as well. This research was successful in that experimental samples bore definite compositional semblance to the archaeological samples. Other researchers have had more success in the past with the appearance of their faience, specifically with the glaze forming (Vandiver 1982, Tite *et al.* 1983). As Miller (2007: 35) suggests, even if the experiments were all successful, and the raw materials were correct, and it all worked out well, it still may not have accurately explained how they produced faience in the past. This experimental work was, however, educational. The

experience itself was beneficial as hands on involvement aids in the understanding of any material. In the future, more experimental research should be undertaken, in order to develop our level of knowledge and expertise in working with this fascinating material. There are no written records from the ancient Egyptians or from the ancient Near East, which describe the recipe for faience material or the craftsmen who produced it. All that remains is for an archaeologist to physically estimate and attempt to replicate the material, to create a contemporary simulation of the archaeological material and essentially reverse engineer faience.

Chapter 8: Discussion

8.1 Interpretation of Results

The results of the SEM-EDS analysis, strontium isotope analysis, and experiments conducted for this research have been presented in their individual chapters. This chapter goes one step further to combine all of the results, discussion and conclusion of each method together. The aim is to form a holistic understanding of the implications of this research to the study of faience. These analytical approaches were employed to develop an understanding of the raw material sources and production methods used for the manufacturing of faience found at Abydos, Egypt. In order to achieve this, a methodology was subsequently developed to determine the difference between groups of faience beads based on time periods spanning the Middle to the New Kingdom. The methodology will be presented first in this chapter, and then the observed changes in technology over time will be discussed, along with the question of whether faience production was consistent during the period of interest. After that, the questions posed in Chapter 1 will be addressed according to the results of the various analytical methods employed.

8.2 Developing a Methodology

Since several different analytical methods were employed for this research, each set of results was tested against the results of the others. The SEM-EDS results were compared with the strontium isotope results in order to determine if the conclusions about alkali sources were likely to be correct. These results were combined with those of the qualitative methods used in order to create a flow chart showing the reverse engineering of faience beads. This was then used to create replicas to test the results.

8.2.1 SEM-EDS vs. Strontium Isotope Analysis

The SEM is a powerful tool for obtaining information about the surface microtopography of samples and, because of this, it was possible to establish the glazing methods of the faience beads studied. The EDS system was utilised to distinguish and analyse the chemical composition of the beads. The results of these tests were used to draw conclusions regarding the alkali, silica, and colourant source/sources, along with other elements present in the material. Strontium isotope analysis was also undertaken to investigate the alkali source, and in general the calcium/strontium source of the faience samples. The SEM-EDS results were

compared to the strontium isotope results to determine if the same conclusions on the alkali source are reached. It should be noted that there are some major differences between these two methods. SEM-EDS is relatively cheap, fast and accessible, but the limits of detection are not as good as the TIMS, which is used for the strontium isotope analysis (Hurcombe 2007: 78). This is because the SEM-EDS measures the element concentration whilst the TIMS measures the isotopic abundance. Strontium isotope analysis can be expensive and difficult to access as there are few facilities capable of conducting such work in Britain. However, one of the benefits of strontium isotope analysis is its ability to investigate the origin of the faience samples based on their strontium ratios (see Chapter 6).

As concluded at the end of Chapter 7, the SEM-EDS results and the strontium isotope results support each other. They both conclude that the alkali source was plant ash (for the samples that were analysed using both methods). However, several beads have low levels of potassium and manganese and these beads could have been produced with natron as the alkali. The strontium concentration levels correlate with this finding. However, the best way to compare the SEM-EDS data with that of the isotope data is by comparing Na_2O/K_2O, Na_2O/MgO, and Na_2O/CaO ratios.

Tite and Shortland (2008: 66) used Na_2O/K_2O ratios to divide Egyptian faience produced with copper as the colourant (which is the case with these samples) into two chronological groups: the first being the Middle Kingdom and New Kingdom faience, which has a range of ratios from 2.3 to 2.5 (never higher than 10), indicating that plant ash was used as the alkali. The second group, Third Intermediate Period faience, has an average ratio that is greater than 10 (usually higher than 40), suggesting natron as the alkali source. The ratio range of interest for the Abydos faience beads is the first group of the Middle and New Kingdom. At Abydos, all but one faience sample fell into the range of 2.5-10. The one exception, Manchester 4075-3, has a ratio of 13.02, which is higher than that of most plant ash ratios, but is still much lower than the average of 40 for natron. Therefore, this bead is either a high-ratio plant ash or possibly the result of the use of mixed alkali. This indicates that the alkali source for the faience bead samples was plant ash (Table 8.1) (Tite and Shortland 2008: 204).

Another ratio used for determining the alkali source is Na_2O/MgO since magnesium is associated with plant ash rather than sodium. In natron, the Na_2O/MgO should have a ratio of less than 4.2 (Tite *et al.* 2007: 1571). At Abydos, only nine beads were consistent with, or lower than, the expected ratio (Figure 8.2). This could be due to a few of the beads having low or undetectable amounts of

magnesium (only three beads had levels of magnesium that are above the limits of detection for that element). This makes the ratio disproportionate.

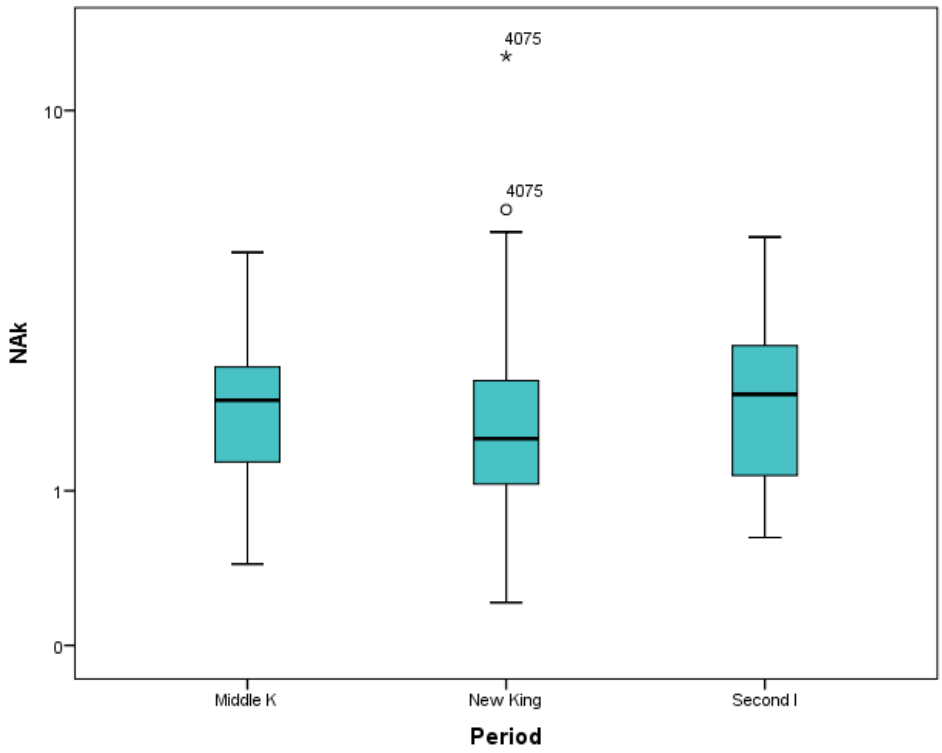


Figure 8.1: The Na_2O/K_2O ratio in the Abydos samples based on time period showing that all but one of the isotope and SEM-EDS samples fall within the plant ash range, <10.

The Na_2O/CaO ratios for nine of the faience samples are higher than the 2.1 ratios for plant ash suggested by Tite *et al.* (2007) (Figure 8.3). A possible explanation for this is that the faience was produced by the addition of the plant ash as a concentrated solution to the faience material, rather than the addition of dry plant ash during mixing, which would then be moistened with water and diluted. It would have been time consuming to produce plant ash and some of the isotope samples indicate 'well ashed' plant ash in very high concentration levels, requiring extensive ashing of large quantities of plants. Therefore, a solution of the ash in water would have made the alkali resource last longer by dilution in certain samples. Very little alkali would have been necessary to produce faience of the required quality, whereas with glass much more alkali would have been required to create the liquid consistency needed.

These results show that the alkalis were still present in the faience samples, and that chemical weathering had not affected them or their compositional make-up. The SEM-EDS and strontium isotope analysis results both agree that the alkali

source was indeed plant ash. This demonstrates that both methods are useful for the study of the alkali source of faience.

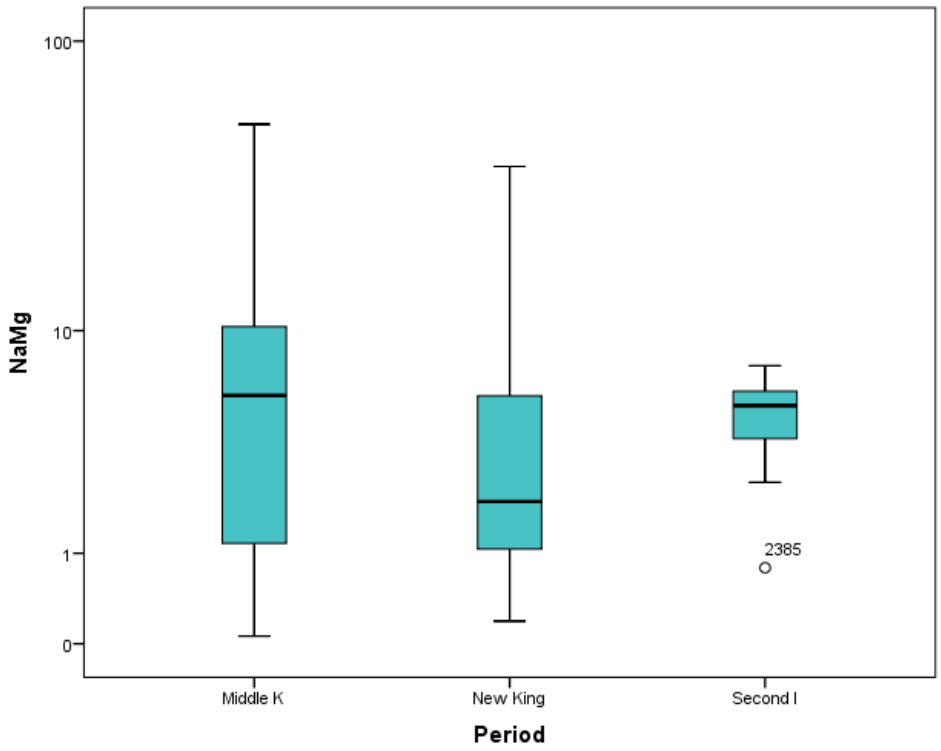


Figure 8.2: The Na_2O/MgO ratios presented by time period have a variable range.

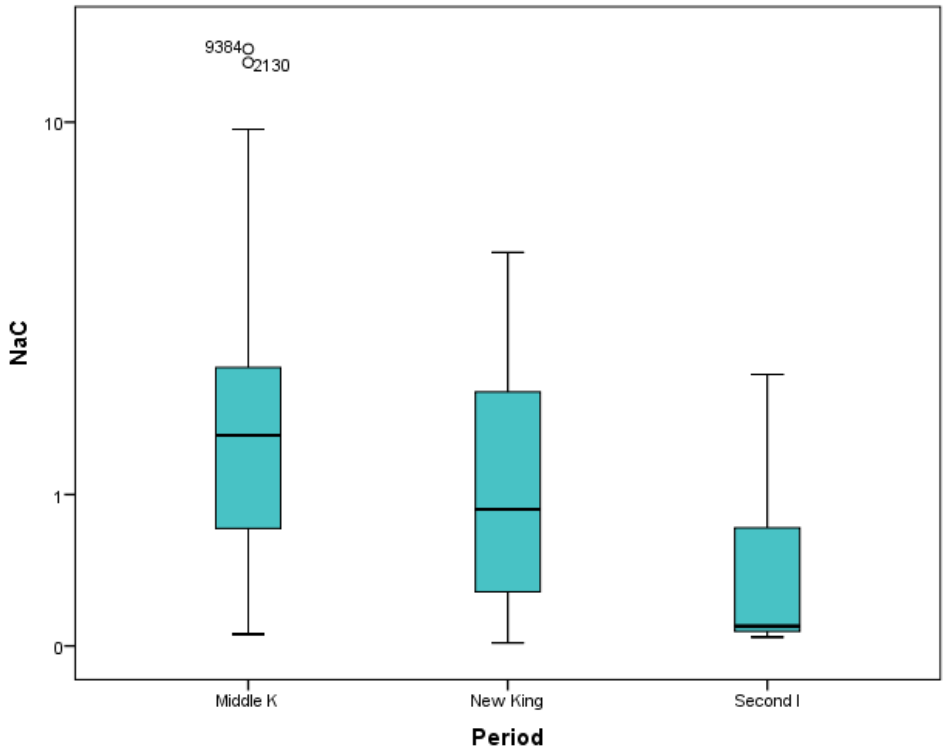


Figure 8.3: Na_2O/CaO ratios by time period, which fall within the expected range for plant ash.

8.2.2 Flow Chart

One of the aims of this research was to develop a methodology for studying the multiple production methods used to manufacture faience. As part of this developing methodology, a flow chart was created which could be used on any faience material from any geographical location and period, to determine how a faience bead was produced; essentially reverse engineering of the faience bead (Figure 8.4). In reverse engineering, the end product (artefact) is studied, and the question of how it was made is asked and answered using analytical methods.

It is important to determine the operational sequence of faience production from the selection of raw materials, to the forming and glazing of the bead, and the cause of its perforation. There are no textual sources for the methods of faience production (Martinon-Torres 2008: 16, Freestone 2008: 97). Figure 8.4 shows the flow chart and the reverse engineering of two faience beads, one Middle Kingdom and one New Kingdom, used to aid researchers by showing the operational sequence. The end product is represented on the top of the image with the raw materials and production methods at the bottom.

Each step represented in the flow chart required a different analytical method to determine the technological choice leading to the end product. A microscope was used to determine simple production methods, such as whether the bead was modelled or moulded, pierced or reed perforated. The SEM images allow the determination of the glazing method. EDS identified the raw material sources. A Mohs test was conducted to determine the durability and hardness of the glaze and core of the faience artefact. The colour was recorded using Munsell colour charts. These methods represent a combination of qualitative and quantitative analysis, which work well together to form a coherent holistic understanding of the faience bead samples. It was this flow chart, which created the guidelines for the experimental replication aspect of this research.

8.2.3 Experimental Work Vs. SEM-EDS Results

The experimental replication of faience was conducted as a way to check the conclusions drawn by the flow chart and the analytical methods utilised to determine each production step. As presented in Chapter 7, the recipes for the experimental batches were based on the results of the SEM-EDS analysis of the ancient beads. Unfortunately no plant ash could be used due to the difficulty of sourcing the material, and therefore only mineral soda was used. However, all of the other elements were used in quantities as close to the archaeological samples as

possible. The forming method used was modelling because most of the archaeological samples were produced by this method. A mixture of reed modelling and piercing was conducted in order to determine if there are any traits that may indicate the use of one method over another. The beads were fired at varying temperatures and lengths of time, to determine the cause of the hardness of the archaeological samples. Efflorescence and cementation glazing were both attempted to replicate the two methods observed in the archaeological samples.

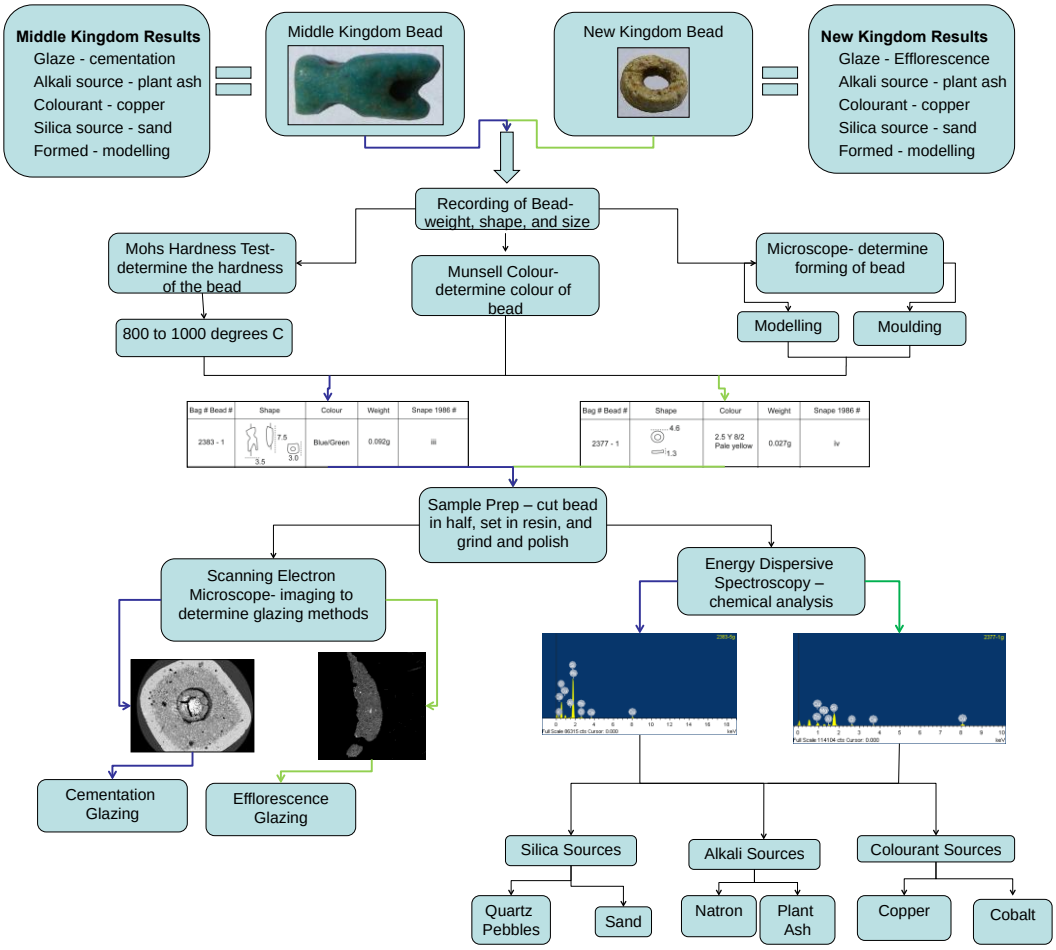


Figure 8.4: Flow chart depicting the process of reverse engineering faience beads.

As concluded in the experimental chapter, the SEM images of the archaeological samples and the experimental samples look very similar. However, all of the experimental samples express characteristics, which are similar to the cementation glazing method, yet they were all glazed by the efflorescence method. The difference between the two glazing methods lies in the quantity of interparticle glass, with the products of the efflorescence method clearly containing more than the cementation method. Some of the experimental beads do contain interparticle

glass, but the majority have very little, which is closer to the products of the cementation glazing method. This suggests that either the characterisation of the glazing methods should be more relaxed, or that the experimental samples are not true faience and perhaps required the addition of more flux or needed to be fired for a longer length of time.

As for the EDS results, the experimental faience samples are compositionally very similar to the archaeological samples, with the only difference being the higher sodium and lower potassium levels (due to the difference in alkali source). Overall, the experimental samples were similar to the archaeological ones in appearance and production methods, although there were slight variations in glaze, colour, and quality. This could be due to the lack of experience in faience production as well as variations in the raw material sources. The methodology that was developed for faience analysis was overall very successful, and could be applied to other faience material of any age, production centre, or artefact type.

8.3 Technology Over Time

The main goal of this research was to determine whether faience technology changed from one period to the next due to the introduction of new production methods. This research establishes a baseline for faience bead studies, as it is one of the largest assemblages ever sampled from one site spanning the Middle Kingdom to the New Kingdom. Most studies in the past have centred on one site specifically, such as Amarna (Shortland 2000), which has a specific occupancy date (the New Kingdom). Other studies have aimed at a large chronological spread and they use many different sites and different artefact groups (Kaczmarczyk and Hedges 1983). This research specifically chose Abydos as a case study because it provided many beads from the whole expanse of the time periods of interest and has limited the potential variation in the analysis from analysing different types of artefact and the variation that might happen from site to site. In doing so, an excellent base line for future faience bead studies and a methodology that can be applied to any faience artefact and time period has been created. This section will discuss the results of this research to determine whether or not faience bead technology changed or remained consistent from the Middle Kingdom to the New Kingdom in comparison to past research. The recorded characteristics for each time period will be presented first, followed by a discussion on this research's results in relation to published research.

8.3.1 Expected Characteristics

The Middle Kingdom is often characterised as the period of fine, durable, and brightly glazed faience (Vandiver 1982: 175). Faience beads produced during this time were considered to be the best produced by jewellery makers (Andrews and Van Dijk 2006: 46). The cementation glazing method is observed for the first time, and therefore all three glazing methods are used during this period (Vandiver 1982: 175). Compositionally the faience of the Middle Kingdom is predominately produced with plant ash as the alkali and copper as the colourant (with concentrations of 0.5-5%) (Shortland *et al.* 2006: 522). Faience objects from this time were formed by modelling and shaped over a form (see Table 2.1). The Second Intermediate Period beads are characterised as being similar to those of the Middle Kingdom, in terms of production methods and visual appearance.

The New Kingdom is normally characterised as being the zenith of faience production, with the introduction of new colourants from glass production, which led to new colours never before seen in faience. For example, cobalt was used for blue instead of copper as well as natron being used as the alkali in association with cobalt (Shortland *et al.* 2006: 522). These colours were introduced with the new vitreous material industry, glass. Different methods of faience production were chosen over those used during the Middle Kingdom, such as the increased use of moulds to form intricate designs and led to mass production (Kaczmarczyk and Hedges 1983). New Kingdom faience was also harder, due to the increase in interparticle glass structure of the faience, partly as a result of efflorescence being the main method of glazing with cementation glaze not utilised during this period.

8.3.2 Assemblage Characteristics

The expected variation between the Middle Kingdom and the New Kingdom faience presented above was not apparent in this bead assemblage (see Table 4.16 and Appendix A). The results from this research have demonstrated very little variation, based on time period, in production methods and bead types. The Middle Kingdom and New Kingdom beads are very similar to each other in that the methods for production are variable and there does not seem to be any patterns (Table 8.1). Both assemblages of beads were produced mainly by the modelling formation method, with sand as the silica source, plant ash as the alkali source, and copper as the colourant, with some iron and manganese coloured beads, and varying degrees of hardness in all faience samples (see Appendix H). The only notable variation is the Middle Kingdom bead assemblage that contains one application glazed, carved,

and drilled bead. This bead is actually a stone bead that has a faience glaze (9384-10) and therefore is an oddity on its own. Another unexpected discovery was the presence of the Wollastonite beads, predominantly in the Second Intermediate Period assemblage, though also found in lesser quantities in the Middle Kingdom and New Kingdom, this is possibly the first time that this material has been identified in faience bead assemblages. Also contrary to previous expectations of mass-produced moulded faience, none of the 151 beads were produced using this method even though it is supposedly the predominant formation method used in the New Kingdom according to previous researchers (Shortland 2000, Nicholson and Peltenburg 2000).

Since discussing a bead assemblage based on time period only provides evidence that there is a variety that was unexpected, the discussion below will present the beads as basic types in order to identify the variability in the production methods of these beads.

Period	Middle Kingdom	Second Intermediate Period	New Kingdom
Bead Quantity	81	10	60
Forming Method			
Carved	1	0	0
Moulded	0	0	0
Modelled	80	10	60
Perforation			
Pierced	10	0	20
Reed	70	2	40
Drilled	1	8	0
Glazing			
Efflorescence	53	2	45
Cementation	20 (7 W.)	1 (7 W.)	5 (10 W.)
Application	1	0	0

Table 8.1: The quantity of beads by time period and their production methods (W. represents Wollastonite beads that were possibly produced by cementation).

An attempt to determine if different techniques of bead manufacturing are associated with different bead types and specific to time period was conducted by using the archaeological data (see Table 4.16) and the experimental results (see Chapter 7). Several different types of beads were found within most of the tombs and these bead types seem to be present in all time periods. The colour was recorded for all of the bead types, but there was no correlation between colour and

bead shape. Therefore it is not discussed here and the shape of the bead is the only descriptive factor for bead type. The bead types have been simplified as disc, double disc, cylinder, ball, oval shapes, and a few speciality beads.

Disc beads are the most common bead type found in this assemblage, with 81 beads from the Middle Kingdom (21) and New Kingdom (60), but there is none found in the Second Intermediate Period (possibly biased by the Wollastonite beads) (Table 8.2). Most of the disc beads are produced using modelling over a reed as the formation methods. This was determined based on the experimental work. It would have been very easy to roll faience over a reed, this would then be rolled into a long cylinder and then sections would have been cut forming many beads at controlled widths. However, there are several beads that could have been pierced due to their size and thickness. Both efflorescence and cementation glazing was used for this bead type, indicating that both were easily used. Efflorescence would have been the easiest as the glazing salts would have been mixed with the core material and easily rolled then cut. Cementation would require that the beads be rolled and then covered in the glazing salts which might have required more glazing powder and therefore could be why this method occurs less than the efflorescence method. This might even explain why the double disc beads are all produced by modelling with a reed and glazed by efflorescence as it would be easier to produce the double disc shape by just indenting the bead in the middle segment then cutting it (Table 8.3).

Period	Middle Kingdom	Second Intermediate Period	New Kingdom
Bead Quantity	21	0	60
Forming Method			
Carved	0		0
Moulded	0		0
Modelled	21		36
Perforation			
Pierced	2		7
Reed	19		29
Drilled	0		0
Glazing			
Efflorescence	18		27
Cementation	3		3 (6 W.)
Application	0		0

Table 8.2: Disc beads are the most common type of bead in the whole assemblage (W. represents Wollastonite beads that were possibly produced by cementation).

Period	Middle Kingdom	Second Intermediate Period	New Kingdom
Bead Quantity	3	0	2
Forming Method			
Carved	0		0
Moulded	0		0
Modelled	3		2
Perforation			
Pierced	0		0
Reed	3		2
Drilled	0		0
Glazing			
Efflorescence	3		2
Cementation	0		0
Application	0		0

Table 8.3: Double disc beads are all produced using modelling with a reed and efflorescence.

The second most common type of faience bead is the cylinder bead, which is made in much the same way as the disc bead. These beads are normally modelled over a reed and then cut longer than the disc bead, and predominantly glazed by efflorescence. There are two variations to this production method. The Middle Kingdom bead (9384-10), which is the carved, drilled, and application glaze stone bead mentioned earlier and one pierced New Kingdom bead (2377-2), which is quite thick in comparison to the other cylinder beads and might have been shaped without the use of a reed.

Period	Middle Kingdom	Second Intermediate Period	New Kingdom
Bead Quantity	46	2	10
Forming Method			
Carved	1	0	0
Moulded	0	0	0
Modelled	45	2	10
Perforation			
Pierced	0	0	1
Reed	45	2	9
Drilled	1	0	0
Glazing			

Period	Middle Kingdom	Second Intermediate Period	New Kingdom
Efflorescence	29	1	10
Cementation	9 (7 W.)	1	0
Application	1	0	0

Table 8.4: Cylinder bead type (W. represents Wollastonite beads that were possibly produced by cementation).

Ball beads are a different type of bead all together. Whereas disc beads and cylinder beads were moulded over a reed, these beads were not. All of the ball beads were produced by hand modelling and then piercing the ball to form the perforation. This was determined as the easiest method for production during experimental work, the ball was easily formed by rolling the faience paste in the hand then piercing it (see Chapter 7). To produce the ball by rolling the paste over a reed is quite difficult and the spherical shape is poor. The glaze used for ball bead production varied from the Middle to the New Kingdom as cementation was used in the Middle Kingdom and mostly in the Second Intermediate Period, yet in the New Kingdom the beads occurred in almost equal numbers using cementation and efflorescence. According to previous researchers (Vandiver 1982, Nicholson and Peltenburg 2000) the dominant production method for New Kingdom faience is supposed to be application and efflorescence glazing methods yet this bead assemblage hints at more of a variety.

Period	Middle Kingdom	Second Intermediate Period	New Kingdom
Bead Quantity	4	8	9
Forming Method			
Carved	0	0	0
Moulded	0	0	0
Modelled	4	8	9
Perforation			
Pierced	4	8	9
Reed	0	0	0
Drilled	0	0	0
Glazing			
Efflorescence	0	1	4
Cementation	4	(7 W.)	1 (4 W.)
Application	0	0	0

Table 8.5: Ball beads (W. represents Wollastonite beads that were possibly produced by cementation).

There are three oval beads from the Middle Kingdom and two from the New Kingdom (Table 8.6). The Middle Kingdom oval beads were produced by modelling the faience material over a reed and two were glazed by efflorescence whilst the other was glazed by cementation. The two New Kingdom beads were produced by modelling and then piercing the material and all were glazed by efflorescence. As there are such small numbers of oval beads it is difficult to make any categorical statements regarding their production methods other than the shape was produced by hand. As for the perforation method this could be down to the size of the beads and the desired oval shape as the axis of the perforation varies per bead. The glazing method for this bead type is predominantly efflorescence, which could indicate it was easier to shape the beads with the glazing salts mixed with the core material.

Period	Middle Kingdom	Second Intermediate Period	New Kingdom
Bead Quantity	3	0	2
Forming Method			
Carved	0		0
Moulded	0		0
Modelled	3		2
Perforation			
Pierced	0		2
Reed	3		0
Drilled	0		0
Glazing			
Efflorescence	2		2
Cementation	1		0
Application	0		0

Table 8.6: Oval beads from the Middle and New Kingdom.

The last few bead types are present in low quantities or only in specific time periods so they will be presented her together as speciality samples. The first such bead is possibly a version of a larger pendant (Middle Kingdom 9384-9) and the reason for selecting this bead was to represent the actual pendant which had a similar colour and shape but was much larger than this sample (Chapter 4.2.1.1). Efflorescence, modelling, and then piercing the faience material produced this sample. Also from the Middle Kingdom are two spacer beads (2130-9 and 10, used to string a tiered necklace) and a bead in the shape of a tooth (2383-1). The two spacer beads were produced by efflorescence, modelling and piercing. The tooth

bead was produced by cementation, modelling and piercing. This could indicate that the more elaborate the shape and smaller size of the bead means it would be easier to produce the beads by hand and then pierce the beads than work with a reed to create the perforation or use a mould. This might even continue as a method into the New Kingdom with the sprocket bead (2384-10) as it is produced by the same methods and glazed with efflorescence. However, this is tentative as there are so few beads in these categories that there is not enough consistency in the bead types to create general characteristics.

The variability in faience bead technology based on bead type provides evidence that faience technology did not change from one period to the next. From the Middle Kingdom to the New Kingdom the same types of beads were being produced using the same methods (with slight variation in glazing methods). The only variation on this is the Second Intermediate Period, which lacked certain bead groups, however this might be due to the abundance of Wollastonite beads in this time period and the small quantity of beads representing this time period. The Middle and New Kingdom beads display a range of bead types and possibly a consistency in the technology to produce these types. Disc, double disc, cylinder, ball, and oval all were produced using the same methods with only slight variations in glazing and a few oddities.

The results contradict the findings of previous researchers mentioned above and ultimately lack the variation that was expected in the technology from one period to the next. Previous studies analysed a variety of faience material from one site and from one time period or studied many sites with a variety of faience material over a large time period. This study isolated one site, one faience material type, and a certain window of time. In removing the variations that can happen from site to site (due to access to raw material sources) and different artefact groups (beads are made differently than faience vases), it was possible to isolate the variation in the production methods of beads alone. As beads are relatively simple to make in comparison to other faience material, and are one of the oldest forms of faience material they did not need altering from time period to time period and therefore a lack of technological change is acceptable. Therefore, there does not appear to be any chronological variations in these faience beads and, in fact, according to this faience assemblage, the beads were consistently made in a variety of way for over 900 years. From the Middle Kingdom onwards the tomb assemblages each contained a range of bead artefact types made with a range of manufacturing methodologies.

8.4 Questions Answered

This research project established average compositional groups within a very large body of unique data never previously accumulated. There are a considerable number of questions that this research sets out to answer, some of which are listed below, and addressed separately in order to develop a further understanding of the results of this research.

8.4.1 Chemical Composition Change?

The first question asked in Chapter 1 was whether the chemical composition change over time and, if so, in what ways? The SEM-EDS analysis proved that the chemical composition of this faience assemblage did not change over time.

8.4.2 Compositional Variations?

What are the compositional variations in faience from the Middle to the New Kingdom? It has been argued that faience colourant sources changed from the Middle to New Kingdoms, due to the introduction of glass technology (Shortland 2000). However, this change was not observed in this assemblage. The silica source was sand, the alkali source was plant ash, and the colourant was predominantly copper. Therefore, the answer to this question is that there are no significant compositional variations from one period to the next in beads at Abydos.

8.4.3 Change in Production Methods?

The next question was whether production methods, such as glazing and shaping, changed from one period to the next, and was one favoured more than another? The answer to this question is as above, in that there does not seem to be any variation through time in the production methods. Past researchers have argued that the use of moulds increased in the New Kingdom (Nicholson 2007: 138, Vandiver 1982: 177). However, there are very few beads that could have been produced by such methods. All of the beads seem to have been produced by hand, by modelling the paste. The piercing was either by reed or perforation. However, there are no distinctive trends to indicate that one method was used more than another, based on time period (see Appendix A).

All three glazing methods were used during the Middle Kingdom, but during the New Kingdom efflorescence glazing has been suggested as the preferred method (Vandiver 1982). In this assemblage, only cementation and efflorescence glazing were apparent. There was one case of application, but this was for a stone

bead. This fits with the New Kingdom description, as efflorescence was the primary glazing method used in the Middle and New Kingdom assemblages.

Due to firing temperatures ranging between 800-1000^{o} C, variations in the hardness of faience were expected, however there was no distinctive pattern to this (Maniatis 2009: 13). The only difference between the two periods is that the Middle Kingdom beads seem to be much harder than the New Kingdom ones. This could be due to the firing methods utilised.

The production methods used for the faience beads appear to be consistent throughout the periods in question. Beads from both periods appear to have been formed by modelling, and glazed by efflorescence. There is no production method that was used more during one period and less in another. In other words, the faience was consistently produced, and the craftsmen did not vary the technology as much as has been previously suggested by other researchers. Even Vandiver (1998: 122) stated that she was wrong to emphasise the three glazing methods, as they could have used a combination of methods, and that focussing on glazing distracted from other technological variations.

8.4.4 The Ideal Faience?

What characteristics are 'ideal' or were most valued by those who made faience artefacts, and how can we tell? Past researchers (Shortland 2000) have presented several different theories about what the 'ideal' faience would look like (i.e. colour and glaze quality) and the reasons behind its production (i.e. the imitation of lapis lazuli). This discussion has even stretched so far as to determine if one time period's faience is better than another period's, such as the New Kingdom being the 'zenith' of faience production. These topics will be discussed below to identify what is the ideal faience.

Some researchers have suggested that the significance of the faience material is related to its colour, blue, being symbolic of rebirth, life, and fertility (Section 2.1.3, Gaydarska and Chapman 2008: 63, Jones 2004: 334, Jones and MacGregor 2002: 12). Therefore, the quality of the blue would be very important and this would in turn determine the ideal faience. Yet this argument seems to revolve around the colour blue and even though this is the most common colour, and likely the first colour for faience, it is not the only colour of faience. During the New Kingdom, faience started to be produced using different colourant sources, which created many different colours, purple, black, brown, read, yellow, orange, and polychrome. Very rarely is any significance attached to these colours. Therefore colour is not a good characteristic to determine what is ideal for faience. In this

assemblage, blue remains the dominant colour, although there are other colours present in smaller quantities and it is very difficult to assign any of the colours significance or any of the beads as ideal faience based on their colour.

Another aspect of faience that has been deemed important is the glaze, and its attributes of shine, gloss, and sparkle (Andrews and Van Dijk 2006: 99). This is based on the theory that faience was made to replicate gemstones in colour and shine (Friedman 1998: 15). This is generally accepted, because one benefit of a glossy glaze is that the faience material is usually harder, and therefore more durable, and could last for eternity, which is what the Egyptians desired in all things. As Jones states (2004: 335), 'durability was a desirable aspect of the mechanical properties of most artefacts', including faience. As the quality of the glaze is not only a fashionable attribute but also a functional one, which means durability this would be a good characteristic to identify the ideal faience. In analysing this ideal characteristic to the bead assemblage sampled for this research, the Middle Kingdom faience beads did seem to be more durable and have a brighter, glossier glaze, as determined by the Mohs hardness test and physical observation. Therefore, this would qualify these beads as contestants for ideal faience.

It is difficult to decide whether one period's faience is more ideal than another, because there are no ancient texts to tell us what the Egyptians thought of faience or what they would have wanted from faience as good characteristics (Gosden and Marshall 1999: 170). The artefact is the only primary source from which archaeologists can draw conclusions (Mattingly 2010: 287). All of the technological choices, cultural beliefs, and what the faience artefact communicates about the individual who owned it, will never truly be known (Antonaccio 2010: 38, Hodos 2010: 19, Prown 1993: 16, Schiffer and Skibo 1997: 27). As the two main periods are similar to each other in the way that the beads were produced, it could be interpreted that these were the desired end products. If the craftsmen desired another outcome or a different style of beads, there would have been variations from one period to the next, as the faience production methods improved. However, as proven by this assemblage, the beads are consistent (with the exception of the Second Intermediate Period Wollastonite beads) and therefore were never improved upon. This could also be due to the concept of regional techniques or schools of production (Miller 2007: 136). There could have been one main faience workshop, which produced beads in the same way for generations and, because demand was constant, there was never any need to modify the technology. Therefore, with the colour not being an aspect of ideal faience, the production methods and end

products being similar from one period to the next, the only characteristic that can be used to determine the ideal faience is the quality of the glaze.

8.4.5 What Caused the Changes in Technology?

Another question regarding the technological changes from one period to the next was this, why did they change? Was it due to movement of craftsmen or faience objects, or a change in the raw material sources, or the beginnings of glass production? Since it has been determined that there was very little change from one period to the next in these faience samples, the cause of any change in faience technology from the Middle Kingdom to the New Kingdom can only be speculated upon based on previous research (Vandiver 1982, Shortland 2000, Nicholson and Peltenburg 200).

Middle Kingdom faience was very fine in quality, improving upon 2000 years of technology (Bienkowski and Tooley 1995: 20). New Kingdom faience theoretically improved on Middle Kingdom faience, following the introduction of a new vitreous material, glass (Vandiver 1982). Therefore the technology is said to have changed over time. This new technology was theoretically imported by Near Eastern craftsmen, who came to Egypt during the New Kingdom. This was when Egypt expanded its empire and ruled over much of the Near East, where the origins of glass are thought to be located. Through this conquest, Egyptian craftsmen were able to interact with those from outside the Kingdom of Egypt. This provided the catalyst for the import of new ideas and raw materials from glass and other vitreous material industries. In other words, during this time, the trade of information, workers and materials from the Near East could have influenced faience technology in Egypt. However, the bead assemblages studied for this research does not support any such conclusions, as will be explained below. Furthermore, it would be interesting to investigate if this is the case for other artefact types, such as vessels, and if it was only beads that remained consistent.

8.5 Beads as an Artefact Group

Specific questions were asked about beads as an artefact group, and what they can tell archaeologists about past societies and the cultures that made them (Aldred 1971: 115). This includes their production methods, such as modelling, which is the predominant method utilised in this bead assemblage (discussed above Section 8.3.2). Other questions were asked about the uses of the beads. Were they produced for everyday utilitarian use, or specifically for ritual and mortuary use? The ideas presented here are speculative, because the real answers are not yet known.

Precise information on the find spots of the beads is lacking in Garstang's reports (Snape 1986). What is known is that these beads were found in mortuary assemblages within tombs (Parker Pearson 1999: 7). This is the most common location in which beads are found in Egypt, due to their use in extensive rituals, and the Egyptians' belief in the afterlife (Metcalf and Huntington 1991: 6). However, it is not known whether the beads were made into jewellery, which could have been worn every day until the individual died, or if they were part of a mummy wrap, which would then indicate that the beads were used specifically for ritual activities. This studies attempt to identify use wear patterns, however this was inconclusive. Furthermore, this conceptual division between daily life and ritual activity reflects modern perspectives on the place of religion in society, but in ancient Egypt the beads worn throughout life could also have been used for ritual purposes, and the same beads could have represented social identity in both life and death.

What has been demonstrated by this research is that beads have a wealth of information to provide. Beads were used to determine the variability in faience technology from the Middle Kingdom to the New Kingdom at Abydos. Although there is little variability in how these beads were produced, it is possible that the results would be the same for other faience artefacts found at the same site. It is possible that the faience paste recipe used for beads would not vary significantly from the paste used for vessels, tiles, and other artefacts (until later periods, when clay was added to improve workability). Therefore, studying beads, which number in the thousands, can enable us to make inferences about artefacts that are far fewer in number from the same site. This is by no means the best way to draw such conclusions, due to other variables such as importation, but beads offer this possibility if unique artefacts cannot be sampled.

Chapter 9: Conclusion

9.1 Summary of Key Points

Chapter 1 introduced the research. This included the research statement, the analytical methodology, and the questions that would be asked of the faience material. Also, the overall objectives and aims of the research were presented along with the terminology that would be used throughout the thesis. The main objective of this research was to determine if faience technology changed over time. The Middle Kingdom beads were selected because this period was considered to be the most experimental period for faience, and it immediately preceded the introduction of glass technology (Nicholson and Peltenburg 2000). The Second Intermediate Period beads were analysed to discover if faience changed between the two Egyptian dynasties. The New Kingdom period was selected because it was considered to be the 'zenith' of faience production, and to discover whether or not the introduction of glass changed the basic methods of faience production to include different colourants.

Chapter 2 then presented the background to faience, the first high-tech synthetic material, and beads. Some key points from this chapter were that faience has been produced since 4000 BC and was used in Egypt until the 14th Century AD. Faience was very important to the Egyptian people. People from all walks of life used the material, whether rich or poor, male or female (Andrews 1990). Although initially faience could have been made to imitate lapis lazuli and turquoise, it was used more extensively than the other materials, and its significance depended on its colour, rather than its fabric or the way it imitated other materials.

Faience has a soda lime silica composition. Each of the main elements has several sources. Silica could either be sourced from sand or crushed quartz, and alkali (soda) could either come from Natron or plant ash. The lime could have been included as an impurity in the sand or plant ash, or added deliberately in the form of crushed shells or limestone. Blue was the most common colour, and the colourant to obtain it was usually copper.

There are three steps in the production of faience: forming, glazing, and firing. Because of the lower level of alkali (in comparison to glass) a faience artefact has three distinct layers: the core, glaze, and interparticle glass, which connects all of the layers together. The quantity of interparticle glass depends on the glazing method used. Efflorescence has the most, whereas cementation and application glaze have very little.

This chapter also presented a discussion on beads, because these small objects are considered to be one of the most common finds on archaeological sites, and are some of the oldest representations of artistic artefacts for mankind (Aldred 1971: 115). Stone and faience beads are hard and quite small, so they do not usually break, and they are often lost or buried in mortuary assemblages in Egypt.

Chapter 3 presented information on the site of Abydos, which was selected for this research due to its extensive cemeteries and their chronologies, from the Predynastic to the Late Period. The site was utilised for mortuary practices due to its connections to the Osiris myth, therefore pilgrims from all over Egypt visited the site. Garstang excavated at the site of Abydos from 1900-1909, and the beads analysed in this thesis were found during his excavations. There is a lack of detail in the recording of his excavations, however Snape (1986) was able to compile information on the vast majority of the tombs Garstang excavated. The tombs were selected based on the artefacts in the assemblage, and that information was provided in this chapter.

Chapter 4 presented information specifically related to the methods with which the 151 bead samples were selected, recorded, and prepared for analysis. The samples were selected at random from their assemblages, based on their colour, shape, and quantity, in order to represent the bulk of the assemblage. The samples were then recorded in full, including their size, shape, colour, weight, and hardness, before undergoing sample preparation, which included cutting the beads in half. Half of the bead was then returned to the museum assemblage, and the other half was set in resin. These resin blocks were analysed in all of the analytical methods used for this research. Additionally strontium isotope analysis investigated a sub-sample of 26 beads.

Chapter 5 presented the main analytical method used to analyse these faience samples SEM-EDS. In general (unless stated otherwise) the SEM was run at 20 KeV with a working distance of 20 mm, which is a high enough energy level for full quantitative analysis, but still low enough to limit sodium burn off. Initially SEI was used to inspect each bead for ideal sampling areas. BEI was then utilised as the main imaging mode in order to record the contrast of each layer in the faience bead based on chemical composition. Each sample was subjected to full BEI imaging of the whole bead or in sections, to create a mosaic of the bead. Two areas were then selected as representative profiles of each bead. In these two profile areas, three spot analysis points were selected for EDS in the three different layers (glaze, interparticle, and core) or when there was no distinction in layers (as is the case with a few beads) points were taken at the surface and interior (See Appendix

F). A total of six points per bead were analysed with EDS (Appendix G). All of the EDS analysis was conducted with the sample stage at a tilt of 30^{o} to the electron beam. This was done for the sake of quantitative analysis, as it improves the geometry within the sample chamber. Mineral and Corning standards were used to ensure the accuracy of the quantitative analysis, and the results were excellent, which limited the amount of statistical manipulation needed, such as normalising.

The experiments run on the SEM-EDS were very successful with both elemental mapping and line analysis as excellent tools for identifying the glazing method used, and for mapping the distribution in copper throughout the beads. The theory behind copper migration was evident in both experiments. However, further study of weathering is necessary, as line analysis was not the right tool for this question.

The use of SEM-EDS to determine glazing methods and the chemical composition of the faience beads was successful. The raw material sources were identified for all the beads, though questions remain regarding the Wollastonite beads, and these were addressed in Chapter 6. As for highlighting the technological variation between the time periods, this research showed that a range of technological methods was in use throughout all time periods. The faience beads were consistently produced using the same range of methods from the Middle Kingdom to the New Kingdom at Abydos, and the variations suggested elsewhere were not present within this assemblage or possibly even at this site.

Chapter 6 presented the results of a pilot study using strontium isotope analysis on faience beads. Twenty-six samples were analysed to test whether or not there was any variation in the strontium concentration and ratios from one period to the next. It was found that faience has a much wider range in strontium concentrations than ancient glass, the data being used to compare with the faience results. Two trends were discovered: high strontium concentrations with low strontium ratios, and low strontium concentration values with variable strontium ratios. These trends show a variation in strontium from one period to the next, with the Middle and New Kingdom beads having a wide range of both strontium concentrations and ratios. The Second Intermediate Period beads, which are Wollastonite, did not vary from each other and formed a tight group with one exception, which was made of faience.

The strontium isotope analysis did imply the origin of the faience studied for this research, including the alkalis used. The strontium ratios indicate that all but four of the faience samples could have been produced using local limestone, and therefore it can be reasonably assumed that they were locally manufactured. The

other four samples have ratio levels similar to glass from the Near East, so these faience beads could have been produced with different raw materials, and therefore may have been produced in the Near East.

Chapter 7 set out to answer three questions regarding the hardness of the archaeological faience, the existence of iron prills, and how to determine whether quartz or sand was used as the silica component. Several methods were used to answer these questions, including replication, Mohs hardness test, crystallography, and EBSD.

The experimental replication of the archaeological samples was conducted in order to learn the craft by performing it, and to try to understand each technological decision that the ancient craftsmen made. The three basic steps – forming, glazing and firing – no longer seem as basic as initially stated. The craftsmen had several choices; forming: moulding, modelling, or controlled forming; glaze: the three main types, or a combination of them; firing: all temperature increments between 800-1000^{o}C are appropriate and at a variety of times.

Several experiments were run. Forty-four batches were produced using different raw materials, production processes, firing temperatures and times, and colourants. All batches were made by weight to match the percentage of each element present in archaeological faience materials. The best results were obtained with metallic copper as the colourant source and sand as the silica source. The other elements were helpful but they did not vary much as their sources were consistent as they were synthetic materials. One of the main points of interest to arise from the experimental work is that particle size is crucial to faience workability. The smaller the particle size, the better the material binds, and therefore Arabic gum and other additives are not necessary. The beads were formed using several different methods: either rolling the beads in the hands and piercing them, or using a reed to form the perforation. The end product after firing proves that it is difficult to determine whether the perforation was made by piercing or with a reed. Some key indicators are the remainder of paste on either end, which indicates that a reed was used, or cracks on one end of a ball bead, which indicate piecing due to the pressure of forcing the needle through the bead. The beads were dried and fired in different ways, temperatures, and lengths of time, but altering these variables did not produce highly varied faience.

The Mohs hardness test proved that an increase in the firing temperature produces an increase in the hardness of faience. However, any other variation in hardness between time periods was undetectable because no consistent trends were observed. It was also difficult to replicate the iron prills seen in the

archaeological samples, so more work needs to be conducted on both experiments. As for the experimental analytical methods used during this research, CL and EBSD, both methods worked well but the general methodology of these methods could be developed further. CL was very subjective in that one has to search the entire matrix of the faience object for a suitable particle to study. This means the researcher is looking for a grain of sand in the material. In a desert country like Egypt, sand easily gets into everything, so this method is not as useful in determining the silica source as originally hoped. EBSD on the other hand has great potential for determining the firing temperatures reached in archaeological samples.

Chapter 8 presented a discussion on the results of all of the analytical methods used for this research. This led to the development of a methodology and flow chart on how to study faience material. Then the results were used to answer all of the questions presented in Chapter 1.

9.2 Problems

Several problems and complications arose during the undertaking of this PhD research. These were due to the comparative data issues with faience, the issues associated with only analysing material from one site, and the chronology of the faience samples. This section will present the problems that will be addressed with future work.

9.2.1 Glass Compared to Faience

It has been a tradition of vitreous material researchers to compare glass with faience. This is because both materials have the same chemical composition and require the same basic production methods. However, they generate two very different end products. One is completely liquefied and homogeneous, whilst the other has a layered structure. Is it sensible or reasonable, therefore, to treat these two materials as the same, and to compare them to each other? Chapter 6 demonstrated the usefulness of comparing faience to glass in order to draw conclusions regarding the strontium isotope results. However, generally faience should be treated separately from glass because it is a different product, and it existed as a technology thousands of years before glass. In the future more studies should be undertaken to develop the understanding of faience in its own right, so it will no longer need to be compared to glass.

9.2.2 Abydos

It should be acknowledged that there are limits in studying a single site such as Abydos. Even though the site is being treated as a case study, the variations within one site can be limited due to a limited number of production centres. However, there could have been a possible influx of faience due to importation, from either pilgrims or from trade. Therefore this question must be asked – was the faience brought to Abydos as offerings from around Egypt and the Near East, or was the vast majority of the material made locally? Strontium isotope analysis might aid in determining which is the most likely case, especially considering that four of the beads that were analysed may well indicate the importation of faience to the site.

Another problem with the site of Abydos is that all of the material studied comes from excavations that took place over 100 years ago, and many of the records are missing. The excavations were conducted before scientific methods were used, and the records were only intended as field notebooks or reports to be sent to investors. This can cast doubt on the chronology of the beads analysed for this research, as the information on the tombs is limited in detail, and disturbed contexts are possible. However, the best recorded tombs with beads and artefacts useful for dating were selected for this research, and in the future it would be better to analyse material excavated recently to ensure that the contexts of the samples are known and reliable.

9.2.3 Sample Size

The pilot project (Hammerle 2008) suggested that a larger sample size (from 11 beads to 151) would help determine the technological changes and variations between the two different time periods studied. However, this was not the case. The greater potential is for more work to be done using analytical methods. It was argued that a larger sample group would improve the statistical analysis and distinguish groups based on chemical composition, yet this was also not apparent. This either means that the beads are compositionally similar, or that it would be prudent to analyse a more varied sample set from across Egypt, and preferably from more recent excavations (however this has its own set of logistical complications). In this way, any trends from production centres might be identified, and the variations in faience material might be shown to be due more to region and workshop than to chronology.

9.2.4 Issues of Weathering

In both the SEM-EDS analysis and in the isotope analysis it became clear that weathering of the faience surface glaze could be an issue (Tite and Bimson 1986: 78, Tite and Shortland 2008: 20). Several beads did have discoloured or missing areas of glaze. However during SEM-EDS analysis these areas were avoided, and for strontium isotope analysis these beads were avoided for sampling, and the samples chosen were cleaned. The results of both analyses have shown that weathering is not an issue with these faience beads, because the alkalis would have been the first elements to leach out due to weathering, and this was not the case. The isotope analysis of bead 2379-10 also helped to discredit any issues of weathering, because its core and glaze were tested separately, yet produced the same results for the alkali content.

9.3 Suggestions for Future Research

This research provided a baseline for faience bead analysis from the Middle Kingdom to the New Kingdom at Abydos, Egypt. The research presented the analysis and results of one of the largest sample groups of faience beads ever studied. The research raised some interesting questions regarding production methods, raw material sources, possible local production, and whether faience technology changed from one period to the next. In the future these questions could be addressed with further experimental work, the use of new analytical methods, and by analysing different faience materials to see if the production trends of faience beads match that of other artefact groups. It would be of interest to conduct this very same methodology on faience artefact groups to see if the trends noticed by other researchers exist in different faience types or sites. Presented below are possible suggestions for such research and a few analytical methods that could be attempted.

9.3.1 Experimental Research

What has been learned, above all else, by undertaking the experimental research for this thesis, is that much more needs to be done. The research needs to be expanded to fully identify the reasons hardness varies so much from one bead to the next, and what causes the iron prills to form. It also needs to address why one bead had a good glaze, and the others did not. In addition why the experimental beads, which were produced using efflorescence, contained very little interparticle glass, and appeared on the SEM-EDS images as if they had been made by the

cementation method needs to be explained. There is also a lot more to learn about faience through experimental work, because there is such a lack of knowledge regarding the choices that the craftsmen went through to produce the material. Experimental work should continue to be carried out, as the information gained would aid in answering these questions, and much more. Ancient Egyptian craftsmen had generations of trial and error to produce faience. With key analytical data as to the specific components, experimental research is the only way to truly grasp the methods of faience production.

9.3.2 Application of New Methods

9.3.2.1 THERMOLUMINESCENCE

It would be of interest to undertake thermoluminescence (TL) tests to explore the thermal history of the quartz particles within faience. This test would use the thermal activation characteristic (TAC) method, which tests the 110^{o} C TL peak of enclosed quartz grains (Godfrey-Smith and Ilani 2004: 186) to determine the highest temperature which the quartz has been exposed to. This method has yet to be used on faience and could possibly address the same questions as EBSD and CL with a greater success rate.

9.3.2.2 NEODYMIUM ISOTOPE ANALYSIS

Neodymium (Nd) isotope analysis would be another analytical method that has great potential for faience material, as it has been successfully used for ancient glass when coupled with strontium isotope analysis. Whereas strontium aids in determining the alkali source, Nd would be useful in determining the silica, as it is a rare earth element that is found in association with the mineral sediments of the Nile, in the non-quartz mineral content of silica (Goldstein *et al.* 1984, Scrivner *et al.* 2004: 565, Degryse *et al.* 2009 b: 60, Freestone *et al.* 2009: 37, Degryse *et al.* 2010 a: 383). Since quartz is purer than sand it will contain negligible concentrations of rare earth elements, of which Nd is one. Nd also has the potential to be useful not only for regional studies but also for the investigation of local provenance for faience material. This can be achieved by analysing the composition of a small area of the Earth's crust or river particulates (such as raw material sources) to determine their Nd levels in comparison to the Nd levels of an artefact (Goldstein *et al.* 1984: 234, Tachikawa *et al*. 2004: 3095, Degryse and Schneider 2008: 1993).

9.4 Objectives and Aims Achieved

In Chapter 1 several different objectives and aims were outlined. The first objective was to develop a working methodology for characterising differences in Egyptian faience technology, by using SEM-EDS to determine the compositional variations from one period to the next. This research has been successful in achieving this objective, as the SEM-EDS was used to characterise the silica, alkali, lime, and colourant raw materials used in the production of these beads. The glazing method was also determined.

Another objective was to establish a typology and system for classification of Egyptian faience material, and to establish whether the raw materials changed from one period to the next. However, as there does not seem to be much change from the Middle Kingdom to the New Kingdom in the faience sample, a typology was not created. The faience material is consistent from all three time periods, with only a few variations (mentioned in Chapters 5, 6, 7, and 8). All of the beads do not conform to the expected characteristics assigned to their periods by previous researchers.

Three aims were also created at the beginning of this thesis. The first aim was automatically achieved by carrying out this work – the expansion of the use of analytical methods in Egyptological studies. The application of scientific methods in conjunction with archaeology is an ideal means to help develop a deeper understanding of Egypt and faience. It is, however, the hope that the methods undertaken in this research will be conducted on other faience items in the future, to continue the expansion and improve the understanding of past cultures through their material. As for the second ambitious aim, of creating a working model for the analysis of faience production methods and raw materials, this was achieved (see Figure 8.1). A flow chart of the reverse engineering of faience beads could easily be applied to faience material from any culture and time period. The final aim was to prove whether or not faience technology varied from one period to the next. In fact, faience technology was shown to be more consistent than first thought.

Overall the research conducted here did expand the understanding of faience technology and its different technical implications. Although this did create more questions than answered, it shows that what was considered to be a ‘simple’ method and material is not actually that simple after all.

9.5 Concluding Statements

This research conducted analysis on 151 beads from the Middle Kingdom, Second Intermediate Period, and the New Kingdom, to determine if there was any technological variation from one period to the next. All of the beads were excavated by John Garstang at Abydos, Egypt, and were housed in the Garstang Museum, (University of Liverpool), the Manchester Museum (University of Manchester), and the Bolton Museum. Several details of each faience bead sample were recorded, including Munsell colour, weight, and Mohs hardness. Several different analytical methods were used to explore the changes in Egyptian faience technology over time. The SEM-EDS was utilised to investigate the glazing methods and raw material sources, especially the silica, alkali, and colourants used. Crystallography and EBSD were conducted to determine the silica source and the firing temperatures. Strontium isotope analysis was conducted for the first time on faience, to assess if the method could be used on faience, and to determine the alkali and provenance of the faience sample set used for this pilot project.

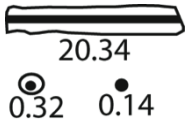
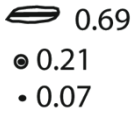
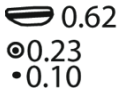
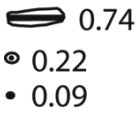
The answer to the overall thesis question is that faience technology at Abydos did remain largely consistent for over 900 years. Mortuary practices in Abydos continued to utilise faience beads of a wide range of bead types produced using a variety of production methods. Even though the new technology of glass production was introduced, along with new raw materials, faience beads continued to be produced using established methods, for this assemblage. It would be fascinating to discover if this continuity in practices was true for all types of faience made and used throughout Egypt during the Middle and New Kingdoms, and future research may prove that this was indeed the case.

Appendix A: Faience Bead Samples

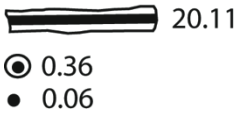
Garstang Museum

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS (mm)	COLOUR MUNSELL	WEIGHT (g)	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
Middle Kingdom E2130-1 427 A'07	0.93 0.21 0.14	Light blue green 5 BG 6/6 Core: same	0.04223	i Long Cylinder I.D.2.b	NA/5	Uneven surface colour and potential rest spots. Glaze is semi-glossy. Modelled. Reed perforated.	Efflorescence	
Middle Kingdom E2130-2 427 A'07	0.91 0.20 0.11	Pale blue green 5 BG 7/2 Core: Very pale blue/white 5B 8/2	0.04247	i Long Cylinder I.D.2.b	NA/5	Uneven surface colour and potential rest spots. Glaze is semi-glossy. Modelled. Reed perforated.	Efflorescence	
Middle Kingdom E2130-3 427 A'07	0.90 0.18 0.07	Light blue green 5 BG 6/6 Core: Very pale blue/white 5 B 8/2	0.04295	i Long Cylinder I.D.2.b	NA/5	Uneven surface colour and potential rest spots. Glaze is semi-glossy. Modelled. Reed perforated.	Efflorescence	
Middle Kingdom E2130-4 427 A'07	0.83 0.21 0.11	Moderate blue green 5 BG 4/6 Core: Very pale blue/white 5B 8/2	0.03323	i Long Cylinder I.D.2.b	NA/5	Uneven surface colour and potential rest spots. Glaze is semi-glossy. Modelled. Reed perforated.	Efflorescence	
Middle Kingdom E2130-5 427 A'07	0.95 0.18 0.09	Dark yellowish green 10 GY 4/4 Core: same	0.03692	i Long Cylinder I.D.2.b	NA/5	Uneven surface colour and potential rest spots. Glaze is semi-glossy. Modelled. Reed perforated.	Efflorescence	

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS (mm)	COLOUR MUNSELL	WEIGHT (g)	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
Middle Kingdom E2130-6 427 A'07	0.13 0.24 0.07	Moderate blue green 5 BG 4/6 Core: Light brown 5 YR 6/4	0.00983	ii Short cylinder with two convex ends I.B.4.f.b	NA/6	Some weathering of glaze. Modelled. Reed perforated. Semi-glossy glaze.	Efflorescence	
Middle Kingdom E2130-7 427 A'07	0.10 0.25 0.06	Moderate blue green 5 BG 4/6 Core: White N9	0.01193	ii Short cylinder with two convex ends I.B.4.f.b	NA/6	Uneven surface colour. Glaze is semi-glossy. Modelled. Reed perforated.	Efflorescence	
Middle Kingdom E2130-8 427 A'07	0.15 0.20 0.11	Moderate blue green 5 BG 4/6 Core: White N9	0.00956	ii Short cylinder with two convex ends I.B.4.f.b	NA/6	Weathered glaze, and poor preservation. Modelled. Reed perforated. Semi-glossy glaze.	Efflorescence	
Middle Kingdom E2130-9 427 A'07	0.16 0.34 0.09 0.08	Light blue green 5 BG 6/6 Core: same	0.01484	iv Spacer	NA/4	Spacer bead. Modelled. Pierced. Semi-glossy glaze.	Efflorescence	
Middle Kingdom E2130-10 427 A'07	0.19 0.35 0.07	Light blue green 5 BG 6/6 Core: same	0.01365	iv Spacer	NA/4	Spacer bead, broken before analysis. Modelled. Pierced. Semi-glossy glaze.	Efflorescence	

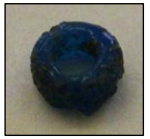
PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS (mm)	COLOUR MUNSELL	WEIGHT (g)	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
Middle Kingdom E9384-1 9 A'06		Moderate blue green 5 BG 4/6 Core: White N9	0.35206	i Long Cylinder I.D.2.b	7/7	Broken large cylindrical bead. Glaze is uneven in colour. Core is slightly pink. Modelled. Reed perforated. Semi-glossy glaze.	Efflorescence	
Middle Kingdom E9384-2 9 A'06		Black N 1 Core: Pale yellowish brown 10 YR 6/2	0.25050	i Long Cylinder I.D.2.b	4/6	Matted glaze. Broken large cylindrical bead. Modelled. Reed perforated.	Cementation	
Middle Kingdom E9384-3 9 A'06		Pale blue green 5 BG 7/2 Core: Pale reddish brown 10 R 5/4	0.03567	iii Standard truncated concave cone I.C.3.d	4/5	Semi-glossy glaze. Oblong or tear drop shape. Uneven colour. Modelled. Reed perforated.	Cementation	
Middle Kingdom E9384-4 9 A'06		Moderate blue green 5 BG 4/6 Core: Pale reddish brown 10 R 5/4	0.04199	iii Standard truncated concave cone I.C.3.d	4/4	Semi-glossy glaze. Oblong or tear drop shape. Uneven colour. Modelled. Reed perforated.	Efflorescence	
Middle Kingdom E9384-5 9 A'06		Brownish black 5 YR 2/1 Core: White N9	0.04082	iii Standard truncated concave cone I.C.3.d	4/4	Semi-glossy glaze. Oblong or tear drop shape. Uneven colour. Modelled. Reed perforated.	Efflorescence	

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS (mm)	COLOUR MUNSELL	WEIGHT (g)	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
Middle Kingdom E9384-6 9 A'06	0.14 0.21 0.10	Brownish black 5 YR 2/1 Core: same	0.00896	iv Barrel disc I.A.1.b	4/4	Semi-glossy. Colour is even. Modelled. Reed perforated.	Efflorescence	
Middle Kingdom E9384-7 9 A'06	0.90 0.23 0.09	Brownish black 5 YR 2/1 Core: same	0.01377	iv Barrel disc I.A.1.b	4/4	Semi-glossy. Colour is even. Modelled. Reed perforated.	Efflorescence	
Middle Kingdom E9384-8 9 A'06	0.09 0.43 0.17	Moderate blue green 5 BG 4/6 Core: Pale reddish brown 10 R 5/4	0.02447	iv Barrel disc I.A.1.b	5/5	Semi-glossy. Colour is even. Modelled. Reed perforated.	Cementation	
Middle Kingdom E9384-9 9 A'06	0.64 0.25 0.09	Moderate blue green 5 BG 4/6 Core: White N9	0.03963	xii Pendant/ special bead	6/6	Very glossy. Colour is even. Modelled. Pierced.	Efflorescence	
Middle Kingdom E9384-10 9 A'06	0.83 0.22 0.34 0.10	Light blue green 5 BG 6/6 Core: Moderate reddish brown 10 R 4/6	0.13521	xiii Decorated long cylinder I.D.2.b	7/6	Very glossy. Colour is uneven. Possibly carved or moulded. Drilled.	Application/ Not faience throughout, Glazed stone	
Middle Kingdom E2435-1 475 A'08	10.43 0.36 0.09	Moderate green 5 G 5/6 Core: Moderate yellowish brown 10 YR 5/4	0.23608	v Long Cylinder I.D.2.b	4/4	Matt glaze. Colour is uneven possible weathering. Modelled. Reed perforated.	Efflorescence	

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS (mm)	COLOUR MUNSELL	WEIGHT (g)	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
Middle Kingdom E2435-2 475 A'08		Pale blue green 5 BG 7/2 Core: White N9	0.28971	v Long Cylinder I.D.2.b	4/5	Semi-glossy glaze. Both ends broken. Colour is uneven, possible weathering. Modelled. Reed perforated.	Cementation	
Middle Kingdom E2435-3 475 A'08		Pale blue green 5 BG 7/2 Core: White N9	0.27634	vi Long Cylinder I.D.2.b	4/4	Semi-glossy glaze. Both ends broken. Colour is uneven, possible weathering. Modelled. Reed perforated.	Cementation	
Middle Kingdom E2435-4 475 A'08		Moderate blue green 5 BG 4/6 Core: Light brown 5 YR 5/6	0.05006	iii Circular I.C.1.a	5/5	Very glossy glaze. Colour is uneven, possible weathering or rest mark. Modelled. Pierced.	Cementation	
Middle Kingdom E2435-5 475 A'08		Moderate yellowish green 10 GY 6/4 Core: Grayish orange 10 YR 7/4	0.01494	i Barrel disc I.A.1.b	5/5	Matt glaze. Both ends broken. Colour is even. Modelled. Reed perforated.	Cementation	
Middle Kingdom 2379-1 359 A'07		Pale blue green 5 BG 7/2 Core: Pinkish gray 5 YR 8/1	0.33943	vii Long Cylinder I.D.2.b	4/4	Semi-glossy glaze. Colour is uneven, possible weathering. Modelled. Reed perforated.	Cementation	

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS (mm)	COLOUR MUNSELL	WEIGHT (g)	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
Middle Kingdom 2379-2 359 A'07	0.55 0.35 0.12	Moderate yellowish green 10 GY 6/4 Core: Pinkish gray 5 YR 8/1	0.10098	vi Short cylinder with two convex ends I.B.4.f.b	4/4	Semi-glossy glaze. Colour is uneven. Modelled. Reed perforated.	Cementation	
Middle Kingdom 2379-3 359 A'07	0.46 0.29 0.08	Grayish yellow green 5 GY 7/2 Core: Pinkish gray 5 YR 8/1	0.06169	vi Short cylinder with two convex ends I.B.4.f.b	4/4	Semi-glossy glaze. Colour is uneven, possible weathering. Modelled. Reed perforated.	Cementation	
Middle Kingdom 2379-4 359 A'07	10.12 0.34 0.10	Moderate blue 5 B 5/6 Core: Pinkish gray 5 YR 8/1	0.17600	vii Long Cylinder I.D.2.b	4/4	Semi-glossy glaze. Colour is uneven, possible weathering. Modelled. Reed perforated.	Cementation	
Middle Kingdom 2379-5 359 A'07	0.71 0.15 0.06	Light blue green 5 BG 6/6 Core: same	0.02504	viii Long Cylinder I.D.2.b	5/5	Semi-glossy glaze. Colour is even. Modelled. Reed perforated.	Efflorescence	
Middle Kingdom 2379-6 359 A'07	0.67 0.22 0.06	Moderate yellowish green 10 GY 7/2 Core: White N9	0.03937	i Standard truncated concave cone I.C.3.d	5/5	Semi-glossy glaze. Colour is even possible weathering. Modelled. Reed perforated.	Efflorescence	

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS (mm)	COLOUR MUNSELL	WEIGHT (g)	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
Middle Kingdom 2379-7 359 A'07	0.10 0.36 0.15	Pale green 10 G 6/2 Core: same	0.01665	ii Barrel disc I.A.1.b	4/4	Semi-glossy glaze. Colour is even, possible weathering. Modelled. Reed perforated.	Efflorescence	
Middle Kingdom 2379-8 359 A'07	0.18 0.24 0.10	Brownish black 5 YR 2/1 Core: same	0.00915	iii Barrel disc I.A.1.b	5/5	Semi-glossy glaze. Colour is even, possible weathering. Modelled. Reed perforated.	Efflorescence	
Middle Kingdom 2379-9 359 A'07	0.14 0.23 0.09	Brownish black 5 YR 2/1 Core: same	0.01104	iii Barrel disc I.A.1.b	5/5	Semi-glossy glaze. Colour is even, possible weathering. Modelled. Reed.	Efflorescence	
Middle Kingdom 2379-10 359 A'07	10.07 10.11 0.17	Light blue green 5 BG 6/6 Core: Pinkish gray 5 YR 8/1	1.10187	v Circular I.C.1.a	6/6	Semi-glossy glaze. Colour is uneven, possible weathering. Modelled. Pierced.	Cementation	
Middle Kingdom 2345-1 330 A'07	0.12 0.29 0.11	Moderate reddish brown 10 R 4/6 Core: same	0.00916	ii Barrel disc I.A.1.b	6/6	Matt glaze. Colour is even, possible weathering. Modelled. Reed perforated.	Efflorescence	
Middle Kingdom 2345-2 330 A'07	0.11 0.29 0.09	Moderate reddish brown 10 R 4/6 Core: same	0.00977	ii Barrel disc I.A.1.b	6/6	Matt glaze. Colour is even, possible weathering. Modelled. Reed perforated.	Efflorescence	

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS (mm)	COLOUR MUNSELL	WEIGHT (g)	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
Middle Kingdom 2345-3 330 A'07	0.14 0.28 0.13	Moderate reddish brown 10 R 4/6 Core: same	0.01052	ii Barrel disc I.A.1.b	6/6	Matt glaze. Colour is even, possible weathering. Modelled. Reed perforated.	Efflorescence	
Middle Kingdom 2345-4 330 A'07	0.25 0.29 0.15	Grayish red 10 R 4/2 Core: same	0.02353	xii Double Barrel disc I.A.1.b	6/6	Matt glaze. Colour is even, possible weathering. Modelled. Reed perforated or pierced.	Efflorescence	
Middle Kingdom 2345-5 330 A'07	0.10 0.28 0.11	Moderate blue 5 B 5/6 Core: same	0.01219	ii Barrel disc I.A.1.b	5/5	Matt glaze. Colour is even, possible weathering. Modelled. Reed perforated.	Efflorescence	
Middle Kingdom 2345-6 330 A'07	0.08 0.28 0.14	Moderate blue 5 B 5/6 Core: same	0.01145	ii Barrel disc I.A.1.b	5/5	Matt glaze. Colour is even, possible weathering. Modelled. Reed perforated.	Efflorescence	
Middle Kingdom 2345-7 330 A'07	0.06 0.23 0.09	Moderate blue 5 B 5/6 Core: same	0.00805	ii Barrel disc I.A.1.b	5/5	Matt glaze. Colour is even, possible weathering. Modelled. Reed perforated.	Efflorescence	
Middle Kingdom 2345-8 330 A'07	0.09 0.25 0.05	Moderate blue 5 B 5/6 Core: same	0.00950	ii Barrel disc I.A.1.b	5/5	Matt glaze. Colour is even, possible weathering. Modelled. Reed perforated. Possibly glass.	Efflorescence	

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS (mm)	COLOUR MUNSELL	WEIGHT (g)	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
Middle Kingdom 2345-9 330 A'07	0.09 0.28 0.11	Moderate blue 5 B 5/6 Core: White N9	0.01126	ii Barrel disc I.A.1.b	5/5	Matt glaze. Colour is even, possible weathering. Modelled. Reed perforated. Possibly glass.	Efflorescence	
Middle Kingdom 2345-10 330 A'07	0.24 0.35 0.22	Moderate blue 5 B 5/6 Core: same	0.04085	ix Circular I.C.1.a	6/6	Matt glaze. Colour is even, possible weathering. Modelled. Pierced.	Cementation	
New Kingdom 2375-1 577 A'08	0.10 0.25 0.12	Light blue green 5 BG 6/6 Core: White N9	0.01108	ii Barrel disc I.A.1.b	6/6	Semi-glossy glaze. Colour is even, possible weathering. Modelled. Reed perforated.	Efflorescence	
New Kingdom 2375-2 577 A'08	0.13 0.27 0.07	Light blue green 5 BG 6/6 Core: White N9	0.01374	ii Barrel disc I.A.1.b	6/6	Semi-glossy glaze. Colour is even, possible weathering. Modelled. Reed perforated.	Efflorescence	
New Kingdom 2375-3 577 A'08	0.17 0.25 0.08	Light blue green 5 BG 6/6 Core: White N9	0.01027	ii Barrel disc I.A.1.b	6/6	Semi-glossy glaze. Colour is even, possible weathering. Modelled. Reed perforated.	Efflorescence	
New Kingdom 2375-4 577 A'08	0.08 0.23 0.10	Light blue green 5 BG 6/6 Core: White N9	0.00876	ii Barrel disc I.A.1.b	6/6	Semi-glossy glaze. Colour is even, possible weathering. Modelled. Reed perforated.	Cementation	

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS (mm)	COLOUR MUNSELL	WEIGHT (g)	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
New Kingdom 2375-5 577 A'08	0.15 0.24 0.10	Moderate blue 5 B 5/6 Core: White N9	0.00851	ii Barrel disc I.A.1.b	5/5	Glossy glaze. Colour is even. Slight weathering. Modelled. Reed perforated.	Efflorescence	
New Kingdom 2375-6 577 A'08	0.06 0.24 0.06	Light blue green 5 BG 6/6 Core: White N9	0.00977	ii Barrel disc I.A.1.b	6/6	Semi-glossy glaze. Colour is uneven, weathering. Modelled. Reed perforated.	Efflorescence	
New Kingdom 2375-7 577 A'08	0.11 0.26 0.09	Light blue green 5 BG 6/6 Core: White N9	0.00620	ii Barrel disc I.A.1.b	6/6	Semi-glossy glaze. Colour is uneven, weathered. Modelled. Reed perforated.	Efflorescence	
New Kingdom 2375-8 577 A'08	0.09 0.25 0.05	Light blue green 5 BG 6/6 Core: White N9	0.00612	ii Barrel disc I.A.1.b	6/6	Semi-glossy glaze. Colour is uneven, weathered. Modelled. Reed perforated.	Efflorescence	
New Kingdom 2375-9 577 A'08	0.10 0.25 0.05	Light blue green 5 BG 6/6 Core: White N9	0.00936	ii Barrel disc I.A.1.b	6/6	Semi-glossy glaze. Colour is uneven, weathered. Modelled. Reed perforated.	Efflorescence	
New Kingdom 2375-10 577 A'08	0.11 0.25 0.06	Light blue green 5 BG 6/6 Core: White N9	0.01385	ii Barrel disc I.A.1.b	6/6	Semi-glossy glaze. Colour is uneven weathering. Modelled. Reed perforated.	Efflorescence	
New Kingdom 2344-1 942 A'09	0.09 0.22 0.09	Brownish black 5 YR 2/1 Core: same	0.0079	NA Barrel disc I.A.1.b	7/7	Semi-glossy glaze. Colour is uneven weathering. Modelled. Reed perforated.	Cementation	

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS (mm)	COLOUR MUNSELL	WEIGHT (g)	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
New Kingdom 2344-2 942 A'09	0.08 0.25 0.09	Brownish black 5 YR 2/1 Core: Pale red 10 R 6/2	0.00726	NA Barrel disc I.A.1.b	7/7	Semi-glossy glaze. Colour is uneven, weathered. Modelled. Reed perforated.	Efflorescence	
New Kingdom 2344-3 942 A'09	0.46 0.56 0.04	Medium bluish green 5 B 5/1 Core: Moderate blue 5 B 5/6	0.16007	NA Circular I.C.1.a	5/5	Matt glaze. Colour is uneven, weathered. Modelled. Pierced.	Wollastonite? Cementation	
New Kingdom 2344-4 942 A'09	0.47 0.56 0.04	Medium bluish green 5 B 5/1 Core: Moderate blue 5 B 5/6	0.14423	NA Circular I.C.1.a	5/5	Matt glaze. Colour is uneven, weathered. Modelled. Pierced.	Wollastonite? Cementation	
New Kingdom 2344-5 942 A'09	0.45 0.55 0.04	Medium bluish green 5 B 5/1 Core: Moderate blue 5 B 5/6	0.17748	NA Circular I.C.1.a	5/5	Matt glaze. Colour is uneven, weathered. Modelled. Pierced.	Wollastonite? Cementation	
New Kingdom 2344-6 942 A'09	0.45 0.51 0.05	Medium bluish green 5 B 5/1 Core: Moderate blue 5 B 5/6	0.17458	NA Circular I.C.1.a	5/5	Matt glaze. Colour is uneven, weathered. Modelled. Pierced.	Wollastonite? Cementation	
New Kingdom 2344-7 942 A'09	0.18 0.50 0.08	Medium bluish green 5 B 5/1 Core: Moderate blue 5 B 5/6	0.04671	NA Barrel disc I.A.1.b	5/5	Matt glaze. Colour is uneven, weathered. Modelled. Pierced.	Wollastonite? Cementation	
New Kingdom 2344-8 942 A'09	0.18 0.48 0.07	Medium bluish green 5 B 5/1 Core: Moderate blue 5 B 5/6	0.06998	NA Barrel disc I.A.1.b	5/5	Matt glaze. Colour is uneven, weathered. Modelled. Pierced.	Wollastonite? Cementation	

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS (mm)	COLOUR MUNSELL	WEIGHT (g)	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
New Kingdom 2344-9 942 A'09	0.21 0.54 0.08	Medium bluish green 5 B 5/1 Core: Moderate blue 5 B 5/6	0.04632	NA Barrel disc I.A.1.b	5/5	Matt glaze. Colour is uneven, weathered. Modelled. Pierced.	Wollastonite? Cementation	
New Kingdom 2344-10 942 A'09	0.15 0.49 0.06	Medium bluish green 5 B 5/1 Core: Moderate blue 5 B 5/6	0.05227	NA Barrel disc I.A.1.b	5/5	Matt glaze. Colour is uneven weathering. Modelled. Pierced.	Wollastonite? Cementation	
New Kingdom 2389-1 649 A'08	0.34 0.38 0.12	Dark reddish brown 10 R 5/4 Core: Moderate reddish brown 10 R 4/6	0.07402	i Barrel disc I.A.1.b	5/5	Semi-glossy glaze. Colour is even. Modelled. Pierced.	Efflorescence	
New Kingdom 2389-2 649 A'08	0.36 0.47 0.12	Moderate reddish brown 10 R 4/6 Core: same	0.05205	i Circular I.C.1.a	5/5	Semi-glossy glaze. Colour is even. Modelled. Pierced.	Efflorescence	
New Kingdom 2389-3 649 A'08	0.37 0.40 0.22	Moderate reddish brown 10 R 4/6 Core: same	0.05190	i Circular I.C.1.a	5/5	Semi-glossy glaze. Colour is even. Modelled. Pierced.	Efflorescence	
New Kingdom 2389-4 649 A'08	10.00 0.32 0.07	Moderate reddish brown 10 R 4/6 Core: same	0.08591	iii Long cylinder with one concave end I.D.5.b.d	5/5	Semi-glossy glaze. Colour is even. Modelled. Reed perforated.	Efflorescence	

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS (mm)	COLOUR MUNSELL	WEIGHT (g)	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
New Kingdom 2389-5 649 A'08	10.00 0.30 0.18	Moderate reddish brown 10 R 4/6 Core: same	0.08664	iii Long cylinder with one concave end I.D.5.b.d	5/5	Semi-glossy glaze. Colour is even. Modelled. Reed perforated.	Efflorescence	
New Kingdom 2389-6 649 A'08	0.39 0.30 0.14	Light green 5 G 7/4 Core: Pale orange 10 YR 8/2	0.02807	xii Small segment-ed bead A.1.a	5/5	Glossy glaze. Colour is even. Modelled. Reed perforated.	Efflorescence	
New Kingdom 2389-7 649 A'08	0.41 0.28 0.10	Light green 5 G 7/4 Core: Pale orange 10 YR 8/2	0.03131	v Small segment-ed bead A.1.a	5/5	Glossy glaze. Colour is even. Modelled. Reed perforated.	Efflorescence	
New Kingdom 2389-8 649 A'08	0.16 0.40 0.13	Grayish green 5 G 5/2 Core: Very pale orange 10 YR 8/2	0.03071	viii Barrel disc I.A.1.b	5/5	Glossy glaze. Colour is even. Modelled. Reed perforated.	Efflorescence	
New Kingdom 2389-9 649 A'08	0.15 0.39 0.10	Grayish green 5 G 5/2 Core: Very pale orange 10 YR 8/2	0.02842	viii Barrel disc I.A.1.b	5/5	Glossy glaze. Colour is even. Modelled. Reed perforated.	Efflorescence	

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS (mm)	COLOUR MUNSELL	WEIGHT (g)	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
New Kingdom 2389-10 649 A'08	0.11 0.40 0.11	Light blue green 5 BR 6/6 Core: Very pale orange 10 YR 8/2	0.02503	viii Barrel disc I.A.1.b	5/5	Glossy glaze. Colour is even. Modelled. Reed perforated.	Efflorescence	
New Kingdom 2384-1 525 A'08	0.44 0.29 0.14	Moderate blue 5 B 5/6 Core: same	0.03892	vi Small segmented bead A.1.a	5/5	Semi-glossy glaze. Colour is even. Modelled. Reed perforated.	Efflorescence	
New Kingdom 2384-2 525 A'08	0.34 0.31 0.05	Moderate green 5 G 5/6 Core: Very pale orange 10 YR 8/2	0.03818	v Small segmented bead A.1.a	5/5	Semi-glossy glaze. Colour is even. Modelled. Reed perforated.	Efflorescence	
New Kingdom 2384-3 525 A'08	0.17 0.33 0.12	Brilliant green 5 G 6/6 Core: Very pale orange 10 YR 8/2	0.02265	iv Barrel disc I.A.1.b	5/6	Semi-glossy glaze. Colour is even. Modelled. Reed perforated.	Efflorescence	
New Kingdom 2384-4 525 A'08	0.12 0.34 0.11	Pale reddish brown 10 R 5/4 Core: same	0.01887	iv Barrel disc I.A.1.b	5/5	Semi-glossy glaze. Colour is even. Slightly weathered. Modelled. Reed perforated.	Cementation	
New Kingdom 2384-5 525 A'08	0.11 0.31 0.11	Dark yellowish orange 10 YR 6/6 Core: same	0.01335	iv Barrel disc I.A.1.b	5/5	Semi-glossy glaze. Colour is even. Modelled. Reed perforated.	Efflorescence	

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS (mm)	COLOUR MUNSELL	WEIGHT (g)	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
New Kingdom 2384-6 525 A'08	0.11 0.30 0.10	Bluish white 5 B 9/1 Core: same	0.01202	iv Barrel disc I.A.1.b	6/6	Glossy glaze. Colour is even. Modelled. Reed perforated. Possibly glass	Efflorescence	
New Kingdom 2384-7 525 A'08	0.14 0.21 0.10	Brownish black 5 YR 2/1 Core: Moderate brown 5 YR 3/4	0.00715	iv Barrel disc I.A.1.b	5/5	Semi-glossy glaze. Colour is even. A bit weathered. Modelled. Pierced.	Efflorescence	
New Kingdom 2384-8 525 A'08	0.08 0.38 0.10	Moderate blue 5 B 5/6 Core: White N9	0.01705	iv Barrel disc I.A.1.b	5/5	Semi-glossy glaze. Colour is even. Slightly weathered. Modelled. Reed perforated.	Efflorescence	
New Kingdom 2384-9 525 A'08	0.16 0.52 0.07	Pale green 10 G 6/2 Core: same	0.04266	iii Barrel disc I.A.1.b	5/5	Semi-glossy glaze. Colour is even. Slightly weathered. Modelled. Pierced.	Wollastonite? Cementation	
New Kingdom 2384-10 525 A'08	0.08 0.50 0.12	Grayish blue green 5 BG 5/2 Core: White N9	0.04092	i Crenelated bead A.I.b	5/5	Semi-glossy glaze. Colour is uneven. A bit weathered. Possibly moulded.	Efflorescence	
New Kingdom 2380-1 492 A'08	0.19 0.55 0.18	Very Pale green 10 G 8/2 Core: Bluish white 5 B 9/1	0.06861	vi Barrel disc I.A.1.b	6/6	Very weathered. Matt and uneven glaze. Modelled, reed perforated.	Cementation	

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS (mm)	COLOUR MUNSELL	WEIGHT (g)	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
New Kingdom 2380-2 492 A'08	0.10 0.29 0.10	Brownish black 5 Y 2/1 Core: same	0.00839	vi Barrel disc I.A.1.b	5/5	Semi-glossy. Very small white specks on the black. Colour is uneven. Some weathering. Modelled. Pierced.	Efflorescence	
New Kingdom 2380-3 492 A'08	0.09 0.26 0.06	Brownish black 5 Y 2/1 Core: same	0.01193	vi Barrel disc I.A.1.b	5/5	Semi-glossy. Very small white specks on the black. Colour is uneven. Some weathering. Modelled. Pierced.	Efflorescence	
New Kingdom 2380-4 492 A'08	0.08 0.28 0.08	Moderate blue 5 B 5/6 Core: White N9	0.01022	vi Barrel disc I.A.1.b	5/5	Semi-glossy. Very small white specks on the black. Colour is uneven. Some weathering. Modelled. Reed perforated.	Efflorescence	
New Kingdom 2380-5 492 A'08	0.12 0.23 0.07	Moderate blue 5 B 5/6 Core: White N9	0.01084	vi Barrel disc I.A.1.b	5/5	Semi-glossy glaze. Uneven colour, some weathering. Modelled. Reed perforated.	Efflorescence	
New Kingdom 2380-6 492 A'08	0.07 0.27 0.07	Moderate blue 5 B 5/6 Core: White N9	0.00874	vi Barrel disc I.A.1.b	5/5	Semi-glossy glaze. Uneven colour, some weathering. Modelled. Pierced.	Efflorescence	
New Kingdom 2380-7 492 A'08	0.08 0.26 0.10	Moderate blue 5 B 5/6 Core: same	0.01092	vi Barrel disc I.A.1.b	5/5	Semi-glossy glaze. Uneven colour, some weathering. Modelled. Reed perforated.	Efflorescence	

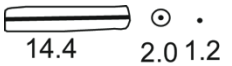
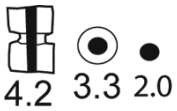
PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS (mm)	COLOUR MUNSELL	WEIGHT (g)	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
New Kingdom 2380-8 492 A'08	0.10 0.25 0.10	Moderate blue 5 B 5/6 Core: same	0.00867	vi Barrel disc I.A.1.b	5/5	Semi-glossy glaze. Uneven colour, some weathering. Modelled. Reed perforated.	Efflorescence	
New Kingdom 2380-9 492 A'08	0.11 0.22 0.06	Moderate blue 5 B 5/6 Core: same	0.01060	vi Barrel disc I.A.1.b	5/5	Semi-glossy glaze. Uneven colour, some weathering. Modelled. Reed perforated.	Efflorescence	
New Kingdom 2380-10 492 A'08	0.10 0.24 0.06	Moderate blue 5 B 5/6 Core: same	0.00960	vi Barrel disc I.A.1.b	5/5	Semi-glossy glaze. Uneven colour, some weathering. Modelled. Reed perforated.	Efflorescence	
Second Inter. Period 2385-1 458 A'08	19.21 3.77 1.71	Moderate blue green 5 BG 4/6 Core: Light brown 5YR 5/6	0.16843	iii Long Cylinder I.D.2.b	6/5	Semi-glossy glaze. Uneven colour, some weathering. Modelled. Reed perforated.	Cementation	
Second Inter. Period 2385-2 458 A'08	8.45 2.88 1.35	Moderate blue 5 B 5/6 Core: Light gray N8	0.08190	iii Long Cylinder I.D.2.b	5/5	Semi-glossy glaze. Uneven colour, some weathering. Modelled. Reed perforated.	Efflorescence	
Second Inter. Period 2385-3 458 A'08	1.83 2.86 1.12	Moderate blue 5 B 5/6 Core: Light gray N8	0.01565	i Long truncated convex cone I.D.1.d	6/6	Semi-glossy glaze. Even colour, some weathering. Possible kiln rest marks. Modelled Pierced.	Efflorescence	

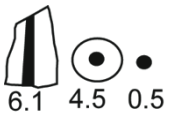
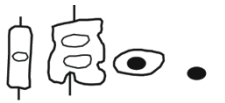
PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS (mm)	COLOUR MUNSELL	WEIGHT (g)	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
Second Inter. Period 2385-4 458 A'08	2.88 2.82 0.98	Light Olive 10 Y 5/4 Core: Pale blue green 5 BG 7/2	0.02980	i Long truncated convex cone I.D.1.d	5/5	Semi-glossy glaze. Even colour, weathering. Modelled. Pierced.	Wollastonite? Cementation	
Second Inter. Period 2385-5 458 A'08	2.88 2.75 0.96	Pale Olive 10 Y 6/2 Core: Very pale green 10 G 8/2	0.02728	i Long truncated convex cone I.D.1.d	5/4	Semi-glossy glaze. Even colour, weathering. Modelled. Pierced.	Wollastonite? Cementation	
Second Inter. Period 2385-6 458 A'08	2.20 2.49 1.20	Pale Olive 10 Y 6/2 Core: Very pale green 10 G 8/2	0.01529	i Long truncated convex cone I.D.1.d	5/5	Semi-glossy glaze. Even colour, weathering. Modelled. Pierced.	Wollastonite? Cementation	
Second Inter. Period 2385-7 458 A'08	3.18 3.02 0.97	Pale olive 10 Y 6/2 Core: Very pale green 10 G 8/2	0.03251	i Long truncated convex cone I.D.1.d	5/5	Semi-glossy glaze. Even colour, weathering. Modelled. Pierced.	Wollastonite? Cementation	
Second Inter. Period 2385-8 458 A'08	2.68 2.80 0.89	Grayish yellow green 5 GY 7/2 Core: Very pale green 10 G 8/2	0.02382	i Long truncated convex cone I.D.1.d	5/3	Semi-glossy glaze. Even colour, weathering. Modelled. Pierced.	Wollastonite? Cementation	

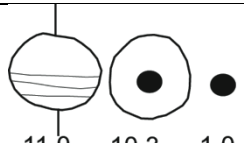
PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS (mm)	COLOUR MUNSELL	WEIGHT (g)	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
Second Inter. Period 2385-9 458 A'08	2.89 2.76 1.21	Moderate yellow green 5 GY 7/4 Core: Very pale green 10 G 8/2	0.02471	i Long truncated convex cone I.D.1.d	5/5	Semi-glossy glaze. Even colour, weathering. Modelled. Pierced.	Wollastonite? Cementation	
Second Inter. Period 2385-10 458 A'08	3.53 3.47 1.36	Moderate yellow green 5 GY 7/4 Core: Very pale green 10 G 8/2	0.04633	i Long truncated convex cone I.D.1.d	5/4	Semi-glossy glaze. Even colour, weathering. Modelled. Pierced.	Wollastonite? Cementation	

Garstang Museum: MSc beads (Hammerle 2008)

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS	COLOUR MUNSELL	WEIGHT GRAM	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
Middle Kingdom E2383-1 498 A'08	7.5 3.0 0.97	Moderate blue green 5 BG 4/6 Core: Pinkish gray 5 YR 8/1	0.092	iii XXXI Tooth	7/8	Shaped like a tooth, with a square top and rectangular body. The glaze is very uniform in colour and matted. Modelled. Pierced.	Cementation	

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS	COLOUR MUNSELL	WEIGHT GRAM	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
Middle Kingdom E2383-2 498 A'08		Moderate blue green 5 BG 4/6 Core: same	0.088	xv Long Cylinder I.D.2.b	8/8	There are bumps along one side, possibly rest marks of the kiln supports. The glaze is very uniform in colour and glossy. Modelled. Reed perforated.	Efflorescence	
Middle Kingdom E2383-3 498 A'08		Moderate blue green 5 BG 4/6 Core: White N 9	0.121	NA Barrel disc I.A.1.b	7/7	The glaze is very uniform in colour and glossy with minor discolouration. Modelled. Reed perforated.	Cementation	
Middle Kingdom E2383-4 498 A'08		Moderate blue green 5 BG 4/6 Core: same	0.042	vi Small segmented bead A.1.a	8/9	The colour of the glaze is uniform except for one side, possible kiln rest. The glaze is very glossy in some areas and matted in others. Modelled. Reed perforated.	Efflorescence	
Middle Kingdom E2383-5 498 A'08		Moderate blue green 5 BG 4/6 Core: same	0.022	NA Small segmented bead A.1.a	8/8	Very uniform colour, however one side seems slightly lighter from where it possibly rested during production. Glossy glaze. Modelled. Reed perforated.	Efflorescence	

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS	COLOUR MUNSELL	WEIGHT GRAM	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
Middle Kingdom E2383-6 498 A'08		Light greenish gray GLEY 1 7/1 Core: same	0.054	xi Circular I.C.1.a	8/8	The glaze is matt and lacks any shine. Possibly weathered. Modelled and pierced.	Cementation	
New Kingdom E2377-1 541 A'08		Pale yellow 2.5 Y 8/2 Core: White N 9	0.027	iv Barrel disc I.A.1.b	4/4	The glaze is very faded or non-existent possibly due to weathering. Modelled. Reed perforated.	Wollastonite? Cementation	
New Kingdom E2377-2 541 A'08		Light greenish gray GLEY 1 7/1 Core: same	0.109	viii Long truncated convex cone I.D.1.d	7/7	Glaze is patchy and shiny in areas while it is non-existent in other areas. Weathered. Modelled. Pierced.	Efflorescence	
New Kingdom E2377-3 541 A'08		Greenish gray GLEY 1 5/1 Core: Pinkish gray 5 YR 8/1	0.065	i Short Barrel IX.B.1.b	7/7	The glaze is matted, possible weathering. Modelled and pierced.	Efflorescence	
New Kingdom E2377-4 541 A'08		Light Yellowish brown 10 YR 6/4 Core: Light greenish gray 5 GY 8/1	0.129	iii Short Barrel IX.B.1.b	7/7	The colour varies and the glaze is patchy. Modelled and pierced.	Efflorescence	

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS	COLOUR MUNSELL	WEIGHT GRAM	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
New Kingdom E2377-5 541 A'08		Light greenish gray GLEY 1 8/1 Core: White N 9	1.081	v Circular I.C.1.a	3/3	The glaze is very worn and faded, possibly weathered. Modelled and pierced.	Cementation	

Manchester Museum

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS	COLOUR MUNSELL	WEIGHT GRAM	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
New Kingdom 4075-1 18 A'08		Moderate blue 5 B 5/6 Core: Pale blue 5 B 8/2	0.03948	i Long Cylinder I.D.2.b	5/6	Even surface colour. Glaze is semi-glossy. Modelled. Reed perforated.	Efflorescence	
New Kingdom 4075-2 18 A'08		Pale green 10 G 6/2 Core: Very pale blue 5 B 8/2	0.07603	i Long Cylinder I.D.2.b	4/4	Even surface colour. Glaze is semi-glossy. Modelled. Reed perforated. Weathered.	Efflorescence	
New Kingdom 4075-3 18 A'08		Grayish blue green 5 BG 5/2 Core: same	0.09563	i Long Cylinder I.D.2.b	4/4	Uneven surface colour. Glaze is semi-glossy. Modelled. Reed perforated.	Efflorescence	

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS	COLOUR MUNSELL	WEIGHT GRAM	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
New Kingdom 4075-4 18 A'08	0.63 0.09 0.10	Moderate blue 5 B 5/6 Core: Pale blue 5 B 8/2	0.03146	i Long Cylinder I.D.2.b	4/4	Even surface colour. Glaze is semi-glossy. Modelled. Reed perforated.	Efflorescence	
New Kingdom 4075-5 18 A'08	0.54 0.09 0.10	Pale blue green 5 B 6/2 Core: Very pale blue 5 B 8/2	0.02791	i Long Cylinder I.D.2.b	3/5	Even surface colour. Glaze is semi-glossy. Modelled. Reed perforated.	Efflorescence	

Bolton Museum

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS	COLOUR MUNSELL	WEIGHT GRAM	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
Middle Kingdom 54.00.75-1 E 105	0.80 0.40 0.10	Very pale orange 10 YR 8/2 Core: same	0.13979	NA Long Cylinder I.D.2.b	2/1	Glaze mostly gone with only patches remaining. Very weathered. Modelled, reed perforated.	Wollastonite? Cementation	
Middle Kingdom 54.00.75-2 E 105	0.70 0.30 0.20	Moderate yellowish brown 10 YR 5/4 Core: Pinkish gray 5 YR 8/1	0.10057	NA Long Cylinder I.D.2.b	2/1	Glaze mostly gone with only patches remaining. Very weathered. Modelled, reed perforated.	Wollastonite? Cementation	

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS	COLOUR MUNSELL	WEIGHT GRAM	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
Middle Kingdom 54.00.75-3 E 105	0.70 0.40 0.10	Grayish orange 10 YR 7/4 Core: Pinkish gray 5 YR 8/1	0.12410	NA Long Cylinder I.D.2.b	2/1	Glaze mostly gone with only patches remaining. Very weathered. Modelled, reed perforated.	Cementation	
Middle Kingdom 54.00.75-4 E 105	0.70 0.40 0.10	Dusky yellowish brown 10 YR 2/2 Core: Brownish black 5 YR 2/1	0.15173	NA Long Cylinder I.D.2.b	3/2	Glaze mostly gone with only patches remaining. Very weathered. Modelled, reed perforated.	Efflorescence	
Middle Kingdom 54.00.75-5 E 105	0.60 0.30 0.10	Very pale orange 10 YR 8/2 Core: Brownish gray 5 YR 4/1	0.17552	NA Long Cylinder I.D.2.b	3/2	Glaze mostly gone with only patches remaining. Very weathered. Modelled, reed perforated.	Wollastonite? Cementation	
Middle Kingdom 54.00.75-6 E 105	1.00 0.40 0.10	Dusky brown 5 YR 2/2 Core: Brownish gray 5 YR 4/1	0.16470	NA Long Cylinder I.D.2.b	3/2	Glaze mostly gone with only patches remaining. Very weathered. Modelled, reed perforated.	Wollastonite? Cementation	
Middle Kingdom 54.00.75-7 E 105	0.80 0.40 0.10	Pale yellowish brown 10 YR 6/2 Core: Pinkish gray 5 YR 8/1	0.08263	NA Long Cylinder I.D.2.b	2/1	Glaze mostly gone with only patches remaining. Very weathered. Modelled, reed perforated.	Cementation	

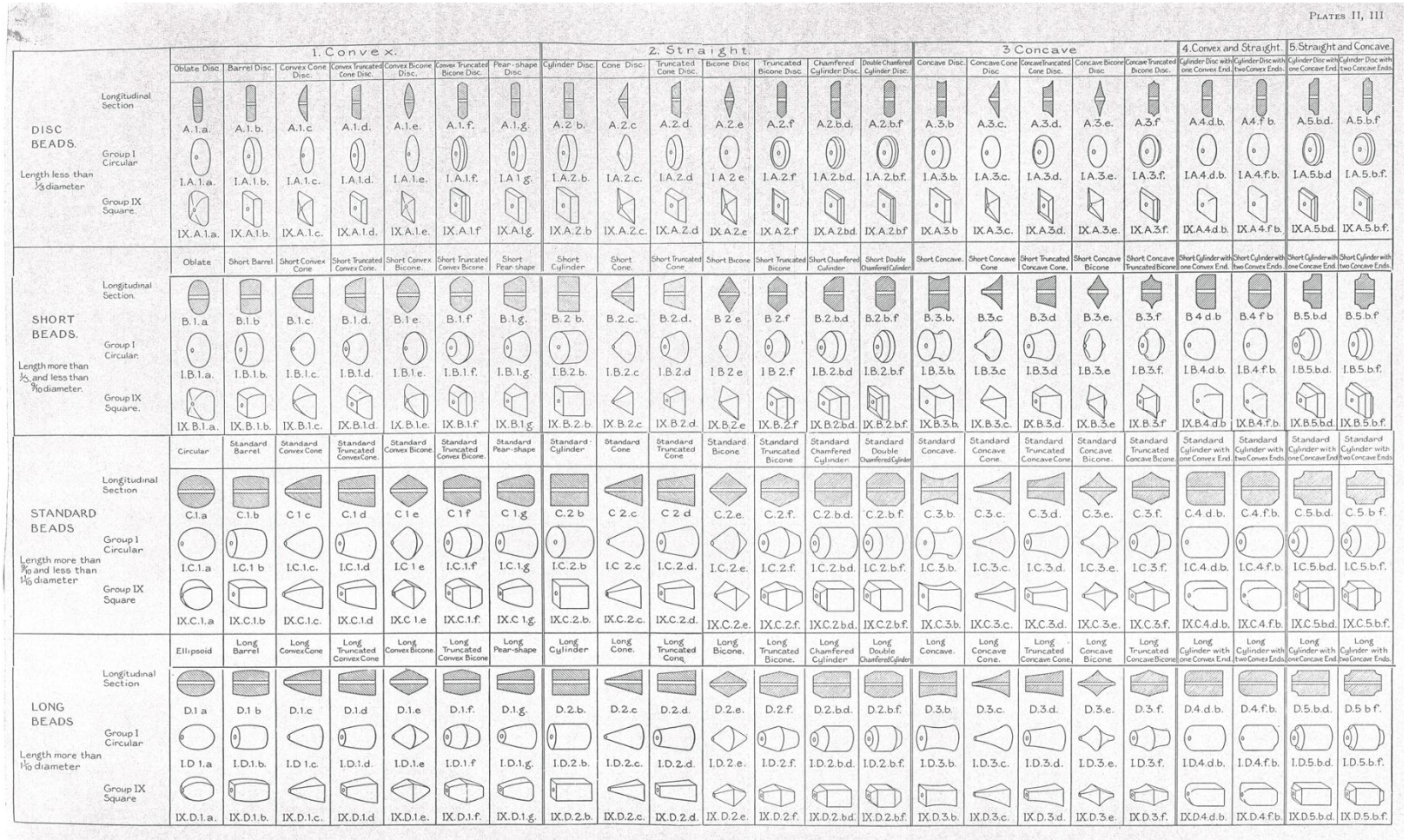
PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS	COLOUR MUNSELL	WEIGHT GRAM	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
Middle Kingdom 54.00.75-8 E 105	0.90 0.40 0.20	Pale yellowish brown 10 YR 6/2 Core: Brownish gray 5 YR 4/1	0.13719	NA Long Cylinder I.D.2.b	2/3	Glaze mostly gone with only patches remaining. Very weathered. Modelled, reed perforated.	Wollastonite? Cementation	
Middle Kingdom 54.00.75-9 E 105	0.90 0.30 0.10	Dark yellowish brown 10 YR 4/2 Core: Brownish gray 5 YR 4/1	0.22121	NA Long Cylinder I.D.2.b	2/2	Glaze mostly gone with only patches remaining. Very weathered. Modelled, reed perforated.	Wollastonite? Cementation	
Middle Kingdom 54.00.75-10 E 105	0.70 0.30 0.10	Pale olive 10 Y 6/2 Core: Pinkish gray 5 YR 8/1	0.11744	NA Long Cylinder I.D.2.b	3/3	Glaze mostly gone with only patches remaining. Very weathered. Modelled, reed perforated.	Wollastonite? Cementation	
Middle Kingdom 54.00.79-1 E 330	0.30 0.30 0.20	Light blue green 5 BG 6/6 Core: same	0.02530	NA Oblate Disc I.A.1.a	4/4	Semi-glossy glaze, slight discolouration at one end. Possible kiln rest mark. Modelled, pierced.	Efflorescence	
Middle Kingdom 54.00.79-2 E 330	0.30 0.30 0.20	Light blue green 5 BG 6/6 Core: same	0.02848	NA Oblate Disc I.A.1.a	4/4	Semi-glossy glaze, slight discolouration at one end. Possible kiln rest mark. Modelled, pierced.	Efflorescence	
Middle Kingdom 54.00.79-3 E 330	1.20 0.30 0.10	Moderate blue 5 B 5/6 Core: same	0.08426	NA Long Cylinder I.D.2.b	5/5	Semi-glossy glaze, slight discolouration at one end. Possible kiln rest mark. Surface is rough and bumpy. Modelled, reed perforated.	Efflorescence	

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS	COLOUR MUNSELL	WEIGHT GRAM	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
Middle Kingdom 54.00.79-4 E 330	1.10 0.30 0.10	Moderate blue 5 B 5/6 Core: same	0.06161	NA Long Cylinder I.D.2.b	5/5	Semi-glossy glaze, slight discolouration at one end. Possible kiln rest mark. Surface is rough and bumpy. Modelled, reed perforated.	Efflorescence	
Middle Kingdom 54.00.79-5 E 330	1.10 0.20 0.10	Light blue green 5 BG 6/6 Core same	0.05026	NA Long Cylinder I.D.2.b	5/5	Glossy glaze. Surface is rough and bumpy. Modelled, reed perforated.	Efflorescence	
Middle Kingdom 54.00.79-6 E 330	1.20 0.20 0.10	Moderate blue 5 B 5/6 Core: same	0.07615	NA Long Cylinder I.D.2.b	5/5	Glossy glaze. Surface is rough and bumpy. Modelled, reed perforated.	Efflorescence	
Middle Kingdom 54.00.79-7 E 330	1.20 0.20 0.10	Moderate blue green 5 BG 4/6 Core: same	0.06845	NA Long Cylinder I.D.2.b	5/5	Glossy glaze. Surface is rough and bumpy. Modelled, reed perforated.	Efflorescence	
Middle Kingdom 54.00.79-8 E 330	1.10 0.20 0.10	Moderate blue 5 B 5/6 Core: Brownish gray 5 YR 4/1	0.08814	NA Long Cylinder I.D.2.b	5/5	Glossy glaze. Surface is rough and bumpy. Modelled, reed perforated.	Efflorescence	
Middle Kingdom 54.00.79-9 E 330	1.10 0.20 0.10	Moderate blue 5 B 5/6 Core: Brownish gray 5 YR 4/1	0.05021	NA Long Cylinder I.D.2.b	5/5	Glossy glaze. Surface is rough and bumpy. Modelled, reed perforated.	Efflorescence	

PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS	COLOUR MUNSELL	WEIGHT GRAM	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
Middle Kingdom 54.00.79-10 E 330	1.10 0.20 0.10	Moderate blue 5 B 5/6 Core: Brownish gray 5 YR 4/1	0.05837	NA Long Cylinder I.D.2.b	4/4	Glossy glaze. Surface is rough and bumpy. Modelled, reed perforated.	Efflorescence	
Middle Kingdom 54.00.79?-1 E 330	1.20 0.20 0.10	Light blue green 5 BG 6/6 Core: same	0.06819	NA Long Cylinder I.D.2.b	4/4	Glossy glaze. Surface is rough and bumpy. Uneven colour. Modelled, reed perforated.	Efflorescence	
Middle Kingdom 54.00.79?-2 E 330	1.10 0.20 0.10	Moderate blue green 5 BG 4/6 Core: same	0.06790	NA Long Cylinder I.D.2.b	5/5	Glossy glaze. Surface is rough and bumpy. Uneven colour. Modelled, reed perforated	Efflorescence	
Middle Kingdom 54.00.79?-3 E 330	1.20 0.20 0.10	Moderate blue green 5 BG 4/6 Core: same	0.06611	NA Long Cylinder I.D.2.b	4/4	Glossy glaze. Surface is rough and bumpy. Uneven colour. Modelled, reed perforated.	Efflorescence	
Middle Kingdom 54.00.79?-4 E 330	1.10 0.20 0.10	Moderate blue green 5 BG 4/6 Core: same	0.06202	NA Long Cylinder I.D.2.b	4/4	Glossy glaze. Surface is rough and bumpy. Uneven colour. Modelled, reed perforated.	Efflorescence	
Middle Kingdom 54.00.79?-5 E 330	1.10 0.20 0.10	Light blue green 5 BG 6/6 Core: Brownish gray 5 YR 4/1	0.07653	NA Long Cylinder I.D.2.b	3/3	Glossy glaze. Surface is rough and bumpy. Uneven colour. Modelled, reed perforated.	Cementation	

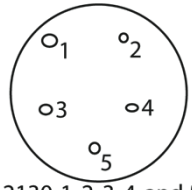
PERIOD CATALOGUE –BEAD # TOMB #	SHAPE MEASUREMENTS	COLOUR MUNSELL	WEIGHT GRAM	SNAPE 1986 # and BECK 1973	HARDNESS CORE/GLAZE	DESCRIPTION FORM, PIERCED, GLAZE	GLAZING METHOD	PHOTO
Middle Kingdom 54.00.79?-6 E 330	1.10 0.20 0.10	Moderate blue 5 B 5/6 Core: same	0.04968	NA Long Cylinder I.D.2.b	4/4	Glossy glaze. Surface is rough and bumpy. Uneven colour. Modelled, reed perforated.	Efflorescence	
Middle Kingdom 54.00.79?-7 E 330	1.20 0.30 0.10	Light blue green 5 BG 6/6 Core: Bluish white 5 B 9/1	0.06314	NA Long Cylinder I.D.2.b	4/4	Glossy glaze. Surface is rough and bumpy. Uneven colour. Modelled, reed perforated.	Efflorescence	
Middle Kingdom 54.00.79?-8 E 330	1.10 0.20 0.10	Light blue green 5 BG 6/6 Core: same	0.07907	NA Long Cylinder I.D.2.b	5/5	Glossy glaze. Surface is rough and bumpy. Uneven colour. Modelled, reed perforated.	Efflorescence	
Middle Kingdom 54.00.79?-9 E 330	1.20 0.20 0.10	Light blue green 5 BG 6/6 Core: same	0.06192	NA Long Cylinder I.D.2.b	4/4	Glossy glaze. Surface is rough and bumpy. Uneven colour. Modelled, reed perforated.	Efflorescence	
Middle Kingdom 54.00.79?-10 E 330	1.10 0.20 0.10	Moderate blue green 5 BG 4/6 Core: Brownish gray 5YR 4/1	0.07143	NA Long Cylinder I.D.2.b	4/4	Glossy glaze. Surface is rough and bumpy. Uneven colour. Modelled, reed perforated.	Cementation	

Appendix B: Beck (1973) Plates II and III

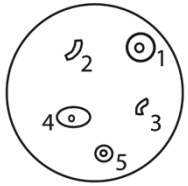


Appendix C: Faience Bead Sample Blocks

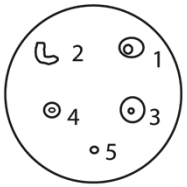
Garstang Museum: Middle Kingdom



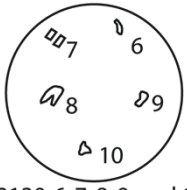
2130-1, 2, 3, 4, and 5



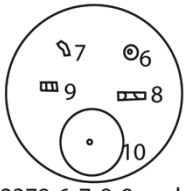
2379-1, 2, 3, 4, and 5



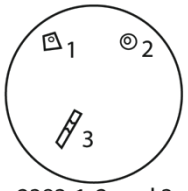
2435-1, 2, 3, 4, and 5



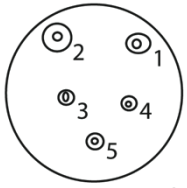
2130-6, 7, 8, 9, and 10



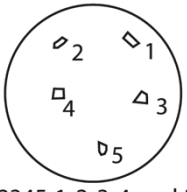
2379-6, 7, 8, 9, and 10



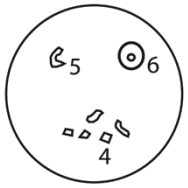
2383-1, 2, and 3



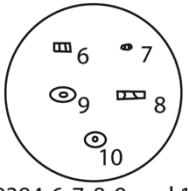
9384-1, 2, 3, 4, and 5



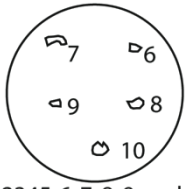
2345-1, 2, 3, 4, and 5



2383-4, 5, and 6

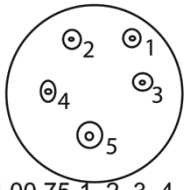


9384-6, 7, 8, 9, and 10

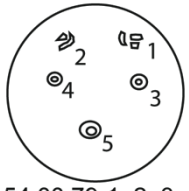


2345-6, 7, 8, 9, and 10

Bolton Museum: Middle Kingdom



54.00.75-1, 2, 3, 4, and 5



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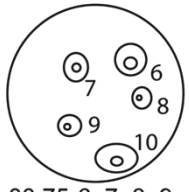
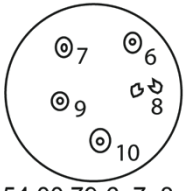
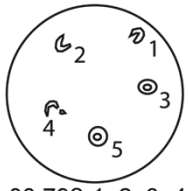


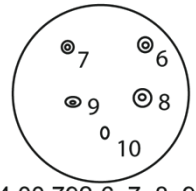
54.00.75-6, 7, 8, 9, and 10



54.00.79-6, 7, 8, 9, and 10

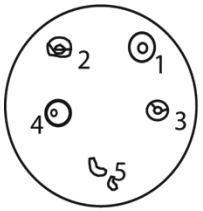


54.00.79?-1, 2, 3, 4, and 5

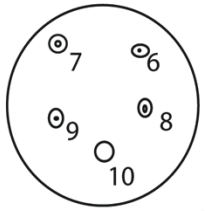


54.00.79?-6, 7, 8, 9, and 10

Garstang Museum: Second Intermediate Period

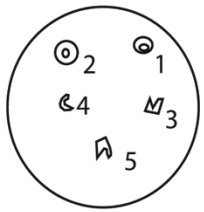


2385-1, 2, 3, 4, and 5



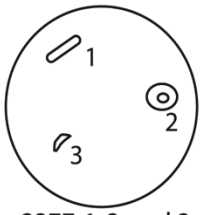
2385-6, 7, 8, 9, and 10

Manchester Museum: New Kingdom

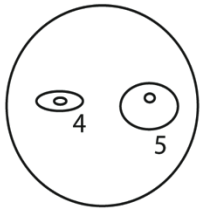


MAN 4075- 1, 2, 3, 4, and 5

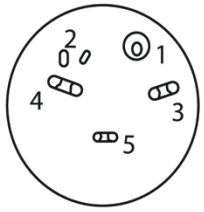
Garstang Museum: New Kingdom



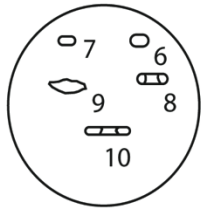
2377-1, 2, and 3



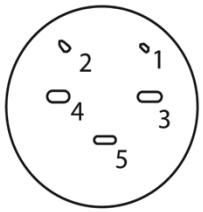
2377-4 and 5



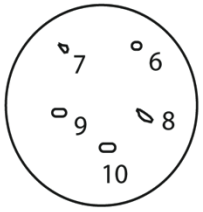
2384-1, 2, 3, 4, and 5



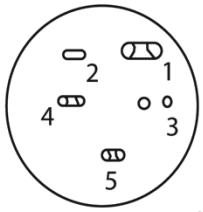
2384-6, 7, 8, 9, and 10



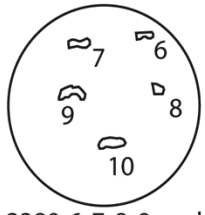
2375-1, 2, 3, 4, and 5



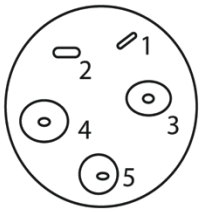
2375-6, 7, 8, 9, and 10



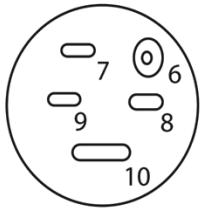
2380-1, 2, 3, 4, and 5



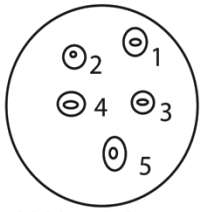
2380-6, 7, 8, 9, and 10



2344-1, 2, 3, 4, and 5



2344-6, 7, 8, 9, and 10



2389-1, 2, 3, 4, and 5

2389-6, 7, 8, 9, and 10

Appendix D: Corning Glass Standards Session Analysis

DATE	POINT	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	TOTAL
28/09/2010	Beginning	71.65	0.89	6.34	2.31	12.73	3.19	1.72	<0.47	2.22	1.82	102.86
28/09/2010	End	71.84	1.25	6.47	2.79	12.72	3.10	1.93	<0.47	1.92	1.70	103.70
30/09/2010	Beginning	71.17	0.73	6.41	2.22	13.17	3.08	1.86	<0.47	2.24	1.79	102.67
30/09/2010	End	71.60	0.80	5.98	2.46	12.72	3.00	1.75	<0.47	2.17	1.56	102.04
05/10/2010	Beginning	71.53	0.88	6.52	2.21	12.44	3.24	1.70	<0.47	2.17	1.83	102.52
05/10/2010	End	71.44	1.03	6.26	2.48	12.80	3.10	2.24	<0.47	2.23	1.72	103.30
12/10/2010	Day	70.08	0.97	6.24	2.56	12.49	3.07	1.81	<0.47	2.01	1.83	101.07
02/02/2011	Day	75.91	1.75	6.38	2.97	6.51	2.79	1.74	<0.47	2.12	1.56	101.75
03/02/2011	Day	65.10	1.60	7.15	2.89	13.45	3.62	2.31	<0.47	2.25	1.72	100.09
04/02/2011	Beginning	63.93	1.66	6.98	2.91	13.76	3.52	2.33	<0.47	2.66	1.76	99.52
04/02/2011	End	64.55	1.40	7.19	2.49	13.38	3.54	2.34	<0.47	2.24	1.79	98.93

DATE	POINT	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	TOTAL
08/02/2011	Beginning	63.73	1.64	6.88	2.72	13.70	3.52	2.30	<0.47	2.36	1.80	98.65
08/02/2011	End	66.90	1.35	7.17	2.42	14.00	3.59	2.44	<0.47	2.50	1.79	102.15
09/02/2011	Beginning	65.32	1.61	7.04	2.75	13.71	3.41	2.36	<0.47	2.33	1.54	100.08
09/02/2011	End	64.89	1.49	7.24	2.64	13.98	3.50	2.08	<0.47	2.35	1.57	99.74
10/02/2011	Beginning	64.82	1.19	6.69	2.15	13.16	3.26	2.23	<0.47	2.47	1.60	97.57
10/02/2011	End	64.29	1.50	6.86	2.49	13.55	3.45	2.13	<0.47	2.59	1.66	98.52
16/02/2011	Beginning	63.89	1.69	7.02	2.78	13.60	3.44	2.49	<0.47	2.47	1.80	99.18
16/02/2011	End	65.79	1.67	7.02	2.73	13.75	3.49	2.40	<0.47	2.46	1.74	101.06
17/02/2011	Beginning	65.41	1.29	6.93	2.37	13.59	3.38	2.30	<0.47	2.57	1.79	99.62
17/02/2011	End	65.57	1.71	6.94	2.76	14.04	3.49	2.16	<0.47	2.29	1.85	100.81
18/02/2011	Beginning	63.19	1.71	6.94	2.95	13.58	3.33	2.31	<0.47	2.29	1.48	97.78
18/02/2011	End	65.68	1.31	7.25	2.30	13.66	3.47	2.08	<0.47	2.57	1.59	99.91
22/02/2011	Beginning	64.14	1.37	6.99	2.32	13.25	3.38	1.99	<0.47	2.40	1.63	97.46

DATE	POINT	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	TOTAL
22/02/2011	End	64.18	1.53	6.98	2.67	13.64	3.40	2.15	<0.47	2.36	1.60	98.52
24/02/2011	Beginning	66.60	1.58	7.10	2.54	13.88	3.52	2.48	<0.47	2.49	1.62	101.81
24/02/2011	End	62.64	1.47	6.82	2.48	13.17	3.23	2.07	<0.47	2.43	1.78	96.09
25/02/2011	Beginning	63.84	1.75	7.02	2.82	13.63	3.45	2.33	<0.47	2.52	1.60	98.95
25/02/2011	End	66.81	1.17	7.17	2.33	13.92	3.48	2.45	<0.47	2.38	1.96	101.67
01/03/2011	Beginning	65.90	1.32	7.14	2.25	13.57	3.53	2.28	<0.47	2.78	1.54	100.32
01/03/2011	End	65.54	1.32	7.22	2.17	13.13	3.57	2.39	<0.47	2.60	1.85	99.79
02/03/2011	Beginning	64.72	1.43	6.79	2.44	12.91	3.43	2.22	<0.47	2.73	1.66	98.34
02/03/2011	End	64.91	1.71	7.15	1.59	13.96	3.53	1.84	<0.47	2.62	1.59	100.13
03/03/2011	Beginning	64.75	1.59	7.09	2.65	13.37	3.47	2.15	<0.47	2.46	1.64	99.17
03/03/2011	End	64.04	1.39	6.88	2.43	13.36	3.48	2.36	<0.47	2.23	1.69	97.86
04/03/2011	Beginning	64.93	1.66	7.15	2.72	13.63	3.48	2.12	<0.47	2.67	1.69	100.05
04/03/2011	End	66.48	1.69	7.47	2.72	13.35	3.59	2.22	<0.47	2.78	1.82	102.13

DATE	POINT	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	TOTAL
08/03/2011	Beginning	64.90	1.60	7.14	2.71	13.18	3.61	2.04	<0.47	2.79	1.75	99.73
08/03/2011	End	65.21	1.15	7.04	2.25	13.41	3.38	2.30	<0.47	2.67	1.64	99.06
09/03/2011	Beginning	65.89	1.18	7.15	2.32	13.62	3.58	2.45	<0.47	2.53	1.80	100.53
09/03/2011	End	66.70	1.53	7.44	2.64	13.92	3.58	2.23	<0.47	2.36	1.71	102.11
10/03/2011	Day	65.70	1.86	6.98	2.87	13.79	3.64	2.48	<0.47	2.57	1.81	101.70
11/03/2011	Beginning	64.39	1.45	7.19	2.40	12.91	3.47	2.20	<0.47	2.46	1.56	98.03
11/03/2011	End	66.96	1.76	7.26	2.65	13.56	3.68	2.14	<0.47	2.59	1.70	102.30
16/03/2011	Beginning	65.64	1.66	7.31	2.67	13.54	3.60	2.50	<0.47	2.61	1.69	101.22
16/03/2011	End	65.12	1.60	7.20	2.75	12.88	3.56	2.05	<0.47	2.46	1.73	99.36
17/03/2011	Beginning	65.11	1.50	7.16	2.61	13.32	3.53	1.98	<0.47	2.49	1.67	99.37
17/03/2011	End	67.24	1.38	7.22	2.46	13.93	3.61	2.26	<0.47	2.67	1.69	102.48
18/03/2011	Beginning	64.91	1.23	7.10	2.20	13.10	3.40	2.00	<0.47	2.65	1.78	98.38
18/03/2011	End	66.89	1.53	7.33	2.65	13.69	3.65	2.35	<0.47	2.62	1.89	102.64

DATE	POINT	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	TOTAL
22/03/2011	Beginning	66.04	1.67	7.31	2.73	13.44	3.57	2.22	<0.47	2.55	1.69	101.21
22/03/2011	End	66.50	1.69	7.48	2.75	13.44	3.67	2.40	<0.47	2.57	1.66	102.15
23/03/2011	Beginning	64.73	1.61	7.29	2.70	13.21	3.47	1.87	<0.47	2.44	1.66	98.99
23/03/2011	End	66.51	1.65	7.35	2.72	13.56	3.70	2.60	<0.47	2.87	<0.69	100.97
24/03/2011	Beginning	65.30	1.41	7.07	2.48	13.25	3.48	2.30	1.16	2.33	1.63	100.42
24/03/2011	End	63.80	1.40	7.16	2.46	12.46	3.48	2.33	1.36	2.62	1.98	99.04
25/03/2011	Beginning	64.87	1.58	7.52	2.54	12.97	3.65	2.39	1.29	2.65	1.64	101.10
25/03/2011	End	65.07	1.44	7.10	2.59	13.35	3.54	2.04	1.16	2.38	1.71	100.38
29/03/2011	Beginning	65.70	1.68	7.31	2.56	13.17	3.57	2.16	1.24	2.28	1.69	101.34
29/03/2011	End	65.29	1.36	7.21	2.39	13.38	3.48	2.08	1.29	2.39	1.66	100.52
30/03/2011	Beginning	66.54	1.50	7.15	2.51	13.27	3.51	2.16	1.15	2.68	1.64	102.10
30/03/2011	End	64.42	1.46	7.10	2.54	13.17	3.50	2.50	1.15	2.68	1.87	100.38
31/03/2011	Beginning	64.71	1.75	7.19	2.78	13.15	3.55	2.34	1.40	2.80	1.78	101.46

DATE	POINT	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	TOTAL
31/03/2011	End	65.99	1.37	7.37	2.51	13.42	3.52	2.23	1.26	2.61	1.68	101.97
01/04/2011	Beginning	64.62	1.42	7.10	2.37	13.00	3.57	2.24	1.23	2.50	1.67	99.72
01/04/2011	End	64.57	1.58	7.43	2.62	13.13	3.48	2.22	1.27	2.42	1.71	100.45
05/04/2011	Beginning	63.49	1.52	6.98	2.53	13.04	3.39	2.15	1.22	2.49	1.75	98.56
05/04/2011	End	66.86	1.23	7.11	2.31	13.59	3.51	2.55	1.28	2.57	1.75	102.77
06/04/2011	Beginning	65.79	1.56	7.08	2.64	13.19	3.69	2.27	1.17	2.55	1.65	101.58
06/04/2011	End	65.06	1.44	7.22	2.45	12.77	3.53	2.24	1.20	2.15	1.92	99.97
07/04/2011	Beginning	63.70	1.69	7.12	2.61	13.06	3.58	2.23	1.29	2.43	1.64	99.36
07/04/2011	End	66.57	1.65	7.38	2.81	13.28	3.61	2.15	1.23	2.64	1.65	102.97
11/04/2011	Beginning	65.04	1.58	7.11	2.66	13.46	3.45	2.04	1.26	2.59	1.62	100.82
11/04/2011	End	65.57	1.57	7.46	2.58	13.29	3.68	2.14	1.36	2.71	1.70	102.05
12/04/2011	Beginning	65.61	1.70	7.40	2.76	13.33	3.60	2.22	1.31	2.73	1.68	102.34
12/04/2011	End	64.12	1.59	7.21	2.56	13.14	3.49	2.37	1.25	2.46	1.66	99.87

DATE	POINT	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	TOTAL
13/04/2011	Beginning	64.61	1.51	7.09	2.40	13.09	3.42	2.20	1.15	2.69	1.68	99.84
13/04/2011	End	66.34	1.64	7.16	2.70	13.42	3.46	2.14	1.11	2.63	1.87	102.47
14/04/2011	Beginning	64.85	1.83	7.23	2.84	13.47	3.61	2.21	1.28	2.57	1.66	101.55
14/04/2011	End	64.78	1.33	7.07	2.28	12.93	3.26	2.20	1.13	2.40	1.73	99.11
15/04/2011	Beginning	65.74	1.57	7.44	2.77	13.14	3.58	2.06	1.21	2.76	1.66	101.93
15/04/2011	End	65.75	1.61	7.34	2.66	13.30	3.70	2.03	1.52	2.24	1.85	101.99
18/04/2011	Beginning	66.26	1.64	7.22	2.58	13.48	3.46	2.30	1.22	2.56	7.77	102.49
18/04/2011	End	64.88	1.68	7.08	2.67	13.36	3.58	2.43	1.28	2.62	1.71	101.31
21/04/2011	Beginning	65.77	1.68	7.48	2.79	13.05	3.69	2.40	1.26	2.51	1.80	102.42
21/04/2011	End	64.47	1.63	7.50	2.78	12.99	3.56	2.30	1.34	2.64	1.59	100.80
22/04/2011	Beginning	66.39	1.61	7.41	2.68	13.06	3.61	2.39	1.25	2.82	1.61	102.83
22/04/2011	End	65.93	1.65	7.49	2.70	13.06	3.68	2.53	1.40	2.63	1.74	102.81
25/04/2011	Beginning	65.16	1.32	6.93	2.42	13.07	3.48	2.26	1.11	2.76	1.70	100.22

DATE	POINT	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	TOTAL
25/04/2011	End	66.03	1.60	7.29	2.62	13.47	3.53	2.56	1.17	2.31	1.70	102.27
26/04/2011	Beginning	65.88	1.55	7.57	2.48	13.20	3.66	2.30	1.44	2.50	1.85	102.42
26/04/2011	End	65.98	1.40	7.27	2.42	13.03	3.55	2.18	1.12	2.30	1.79	101.03
29/04/2011	Beginning	65.24	1.13	7.08	2.38	13.12	3.39	2.00	1.16	2.33	1.68	99.50
29/04/2011	End	65.05	1.22	7.10	2.27	13.07	3.45	2.25	1.26	2.30	1.71	99.69
30/04/2011	Beginning	65.53	1.57	7.23	2.68	13.37	3.64	2.27	1.33	2.48	1.87	101.97
30/04/2011	End	65.02	1.55	7.33	2.60	13.15	3.47	2.14	1.13	2.67	1.74	100.81
16/05/2011	Beginning	65.34	1.70	7.36	2.89	13.67	3.49	2.12	1.29	2.42	1.59	101.87
16/05/2011	End	65.05	1.43	7.17	2.51	13.55	3.42	2.20	1.16	2.26	1.76	100.52
17/05/2011	Beginning	66.44	1.22	7.07	2.25	13.23	3.25	2.17	1.18	2.62	1.67	101.10
17/05/2011	End	64.89	1.55	7.29	2.58	13.08	3.37	2.46	1.25	2.59	1.58	100.64
18/05/2011	Beginning	64.68	1.66	7.38	2.56	13.09	3.46	2.05	1.21	2.24	1.65	99.98
18/05/2011	End	64.80	1.64	7.19	2.63	13.14	3.42	2.20	1.26	2.40	1.65	100.33

DATE	POINT	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	TOTAL
28/05/2011	Beginning	66.69	1.43	7.54	2.46	13.34	3.47	2.32	1.18	2.69	1.79	102.92
28/05/2011	End	65.75	1.66	7.65	2.72	13.30	3.54	2.44	1.24	2.37	1.80	102.46
29/05/2011	Beginning	66.23	1.52	7.48	2.50	13.13	3.58	2.52	1.37	2.76	1.71	102.82
29/05/2011	End	67.00	1.66	7.62	2.61	12.94	3.62	2.24	1.21	2.46	1.55	102.92
14/07/2011	Beginning	64.99	1.65	7.48	2.58	12.36	3.53	2.39	1.34	2.64	1.82	100.77
14/07/2011	End	64.94	1.53	7.24	2.50	12.73	3.39	1.93	1.14	2.74	1.48	99.65
15/07/2011	Beginning	66.04	1.51	7.54	2.54	12.87	3.64	2.48	1.30	2.55	1.68	102.16
15/07/2011	End	65.77	1.75	7.56	2.68	12.55	3.64	2.35	1.34	2.76	1.69	102.09
08/09/2011	Beginning	65.58	1.61	8.01	2.32	12.89	3.86	2.34	1.29	2.82	1.76	102.47
08/09/2011	End	63.60	1.68	7.89	2.61	12.52	3.90	2.22	1.37	2.60	1.85	100.24
16/05/2012	Beginning	67.16	1.51	5.81	3.05	14.24	3.12	1.47	0.99	2.17	1.32	100.84
16/05/2012	End	68.29	1.42	5.62	2.78	14.45	3.23	1.93	0.83	2.17	1.28	102.01
19/05/2012	Beginning	67.74	1.43	5.82	3.11	14.49	3.06	1.60	0.87	2.48	1.40	102.00

DATE	POINT	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	TOTAL
19/05/2012	End	67.59	1.46	5.55	2.88	14.39	3.01	1.71	0.77	2.47	1.26	101.08
20/05/2012	Beginning	65.85	1.43	5.73	2.99	14.06	3.07	1.62	1.03	2.41	1.36	99.54
20/05/2012	End	61.00	1.36	7.76	2.08	10.43	3.93	3.03	1.56	6.43	2.26	99.82

Appendix E: Corning Glass Standards Six Spot Analyses

Date	Point	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	Total
22/03/2011	1	65.89	1.79	7.21	2.83	10.69	3.52	2.15	<0.47	2.42	1.76	98.26
22/03/2011	2	67.27	1.61	7.19	2.78	11.16	3.56	2.29	<0.47	2.26	1.85	99.96
22/03/2011	3	65.95	1.62	7.23	2.74	10.48	3.55	2.17	<0.47	2.94	1.61	98.30
22/03/2011	4	66.39	1.59	7.18	2.88	11.25	3.45	2.22	<0.47	2.37	1.58	98.91
22/03/2011	5	67.38	1.78	7.61	2.87	11.36	3.59	2.03	<0.47	2.76	1.79	101.17
22/03/2011	6	65.70	1.65	7.38	2.81	11.57	3.61	2.20	<0.47	2.52	1.46	98.90
23/03/2011	1	66.14	1.30	7.28	2.28	10.22	3.49	2.45	1.16	2.21	1.71	98.24
23/03/2011	2	66.93	1.67	7.28	2.71	10.58	3.67	2.07	1.26	2.88	1.81	100.85
23/03/2011	3	66.69	1.35	7.27	2.25	10.10	3.49	2.52	1.23	2.52	1.84	99.26
23/03/2011	4	65.77	1.52	7.31	2.64	10.66	3.55	2.07	1.39	2.78	1.72	99.41
23/03/2011	5	65.45	1.56	7.28	2.47	10.89	3.62	2.33	1.34	2.63	1.61	99.08
23/03/2011	6	65.79	1.64	7.31	2.71	10.34	3.61	2.39	1.26	2.50	1.66	99.23

Date	Point	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	Total
24/03/2011	1	66.55	1.66	7.28	2.80	10.08	3.62	2.41	1.37	2.80	1.82	100.37
24/03/2011	2	66.46	1.25	7.21	2.27	10.58	3.40	2.30	1.31	2.26	1.74	98.79
24/03/2011	3	67.00	1.75	7.40	3.08	10.82	3.55	2.29	1.37	2.27	1.79	101.85
24/03/2011	4	65.31	1.69	7.38	2.77	10.63	3.55	2.17	1.31	2.33	1.74	98.88
24/03/2011	5	66.94	1.73	7.36	2.81	10.79	3.67	2.17	1.38	2.69	1.60	101.15
24/03/2011	6	66.61	1.43	7.28	2.67	10.12	3.57	2.31	1.33	2.41	1.65	99.36
25/03/2011	1	65.44	1.79	7.43	2.85	10.00	3.64	2.13	1.22	2.97	1.71	99.17
25/03/2011	2	64.95	1.70	7.36	2.62	10.14	3.73	2.18	1.20	2.45	1.74	98.07
25/03/2011	3	65.95	1.74	7.57	2.78	11.05	3.68	2.20	1.49	2.61	1.70	100.76
25/03/2011	4	63.83	1.74	7.36	2.70	10.08	3.54	2.27	1.18	2.80	1.90	97.39
25/03/2011	5	67.45	1.71	7.55	2.69	10.15	3.71	2.33	1.47	2.72	1.90	101.69
25/03/2011	6	64.73	1.67	7.34	2.60	10.37	3.53	2.33	1.33	2.89	1.76	98.55
29/03/2011	1	66.92	1.61	7.40	2.80	11.00	3.72	2.32	1.34	2.62	1.77	101.50

Date	Point	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	Total
29/03/2011	2	64.33	1.59	7.01	2.56	10.30	3.44	2.11	1.32	2.55	1.78	97.00
29/03/2011	3	68.61	1.70	7.64	2.83	10.44	3.70	2.36	1.34	2.54	1.69	102.86
29/03/2011	4	67.27	1.40	7.24	2.43	11.19	3.59	2.29	1.26	2.44	1.72	100.82
29/03/2011	5	65.14	1.71	7.10	2.90	10.79	3.57	2.36	1.18	2.40	1.68	98.83
29/03/2011	6	67.86	1.52	7.23	2.58	10.31	3.65	2.39	1.25	2.48	1.89	101.16
30/03/2011	1	66.68	1.23	7.19	2.34	10.50	3.51	2.39	1.24	2.70	1.59	99.37
30/03/2011	2	66.24	1.80	7.52	2.71	11.29	3.70	2.09	1.22	2.37	1.76	100.69
30/03/2011	3	66.65	1.61	7.40	2.75	11.57	3.56	2.23	1.13	2.43	1.78	101.11
30/03/2011	4	64.36	1.63	7.17	2.74	10.66	3.54	2.17	1.35	2.32	1.54	97.48
30/03/2011	5	68.14	1.51	7.67	2.69	11.20	3.64	2.41	1.14	2.56	1.81	102.76
30/03/2011	6	65.12	1.63	7.28	2.74	11.01	3.61	2.22	1.28	2.66	1.69	99.25
31/03/2011	1	64.62	1.79	7.13	2.90	10.36	3.52	1.94	1.14	2.18	1.58	97.16
31/03/2011	2	66.72	1.69	7.30	2.68	10.57	3.62	2.44	1.20	2.75	1.71	100.66

Date	Point	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	Total
31/03/2011	3	65.82	1.68	7.29	2.72	10.78	3.51	2.36	1.27	2.61	1.58	99.62
31/03/2011	4	66.60	1.74	7.26	2.83	10.60	3.57	2.43	1.30	2.56	1.71	100.59
31/03/2011	5	67.22	1.76	7.61	2.89	10.45	3.72	2.25	1.41	2.65	1.80	101.77
31/03/2011	6	68.30	1.39	7.45	2.59	10.10	3.58	2.06	1.26	2.56	1.77	101.06
01/04/2011	1	66.68	1.50	7.51	2.71	10.36	3.62	2.39	1.32	2.67	1.73	100.50
01/04/2011	2	64.92	1.84	7.02	2.80	10.58	3.56	2.35	1.28	2.42	1.72	98.48
01/04/2011	3	68.01	1.70	7.71	2.72	10.82	3.62	2.51	1.20	2.35	1.67	102.30
01/04/2011	4	67.93	1.72	7.70	2.77	11.13	3.68	2.30	1.29	2.71	1.74	102.97
01/04/2011	5	66.89	1.56	7.42	2.73	10.86	3.57	2.29	1.33	2.66	1.80	101.12
01/04/2011	6	66.67	1.45	7.17	2.63	10.82	3.42	2.39	1.27	2.66	1.85	100.34
05/04/2011	1	67.86	1.65	7.61	2.85	10.74	3.75	2.18	1.24	2.63	1.80	102.32
05/04/2011	2	66.13	1.26	7.24	2.27	10.23	3.53	2.31	1.18	2.33	1.74	98.23
05/04/2011	3	66.51	1.65	7.35	2.78	11.28	3.70	2.17	1.42	2.67	1.78	101.32

Date	Point	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	Total
05/04/2011	4	66.47	1.45	7.23	2.65	10.97	3.62	2.29	1.18	2.67	1.75	100.28
05/04/2011	5	65.80	1.66	7.15	2.64	11.36	3.46	2.23	1.21	2.48	1.59	99.57
05/04/2011	6	65.40	1.10	6.90	2.34	12.78	3.27	2.15	1.34	2.26	1.84	99.38
06/04/2011	1	65.15	1.58	7.18	2.70	10.79	3.47	2.09	1.24	2.32	1.67	98.19
06/04/2011	2	66.00	1.57	7.25	2.70	10.65	3.59	2.34	1.20	2.75	1.66	99.72
06/04/2011	3	66.29	1.65	7.15	2.77	10.38	3.66	2.28	1.30	2.45	1.88	99.80
06/04/2011	4	65.97	1.48	7.31	2.65	10.51	3.55	2.10	1.23	2.60	1.56	98.96
06/04/2011	5	66.17	1.83	7.43	3.00	10.59	3.56	2.07	1.28	2.35	1.59	99.98
06/04/2011	6	67.26	1.70	7.40	2.80	10.79	3.67	2.39	1.25	2.86	1.94	102.06
07/04/2011	1	67.77	1.70	7.67	2.90	10.92	3.63	2.02	1.22	2.37	1.74	101.94
07/04/2011	2	65.39	1.70	7.35	2.50	11.27	3.47	2.37	1.23	2.53	1.63	99.42
07/04/2011	3	65.29	1.73	7.49	2.67	11.08	3.56	2.05	1.22	2.65	1.82	99.54
07/04/2011	4	64.99	1.25	6.99	2.33	10.70	3.45	1.93	1.33	2.58	1.66	97.21

Date	Point	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	Total
07/04/2011	5	66.38	1.63	7.40	2.79	10.06	3.65	2.21	1.37	2.54	1.81	99.82
07/04/2011	6	66.89	1.64	7.49	2.81	11.00	3.61	2.08	1.36	2.32	1.86	101.07
11/04/2011	1	67.85	1.88	7.44	2.94	11.33	3.67	1.96	1.31	2.50	1.85	102.74
11/04/2011	2	66.50	1.26	6.86	2.48	10.69	3.40	2.25	1.19	2.65	1.52	98.81
11/04/2011	3	65.33	1.52	7.09	2.56	10.67	3.40	2.10	1.24	2.33	1.58	97.82
11/04/2011	4	66.62	1.75	7.37	2.81	10.27	3.53	2.34	1.28	2.42	1.65	100.04
11/04/2011	5	66.01	1.63	7.04	2.57	10.45	3.46	2.17	1.19	2.48	1.77	98.50
11/04/2011	6	67.94	1.70	7.58	2.85	10.63	3.63	2.20	1.29	2.92	1.88	102.63
12/04/2011	1	63.93	1.61	7.08	2.63	11.66	3.48	2.19	1.21	2.52	1.57	97.89
12/04/2011	2	66.97	1.77	7.45	2.90	11.26	3.72	2.06	1.26	2.44	1.72	101.55
12/04/2011	3	68.43	1.51	7.58	2.79	10.24	3.73	1.95	1.41	2.77	1.68	102.11
12/04/2011	4	68.73	1.51	7.56	2.67	10.13	3.64	2.26	1.23	2.85	1.75	102.34
12/04/2011	5	66.37	1.18	7.20	2.26	10.01	3.55	2.20	1.27	2.65	1.64	98.34

Date	Point	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	Total
12/04/2011	6	66.12	1.66	7.36	2.82	10.17	3.70	2.32	1.26	2.48	1.61	99.49
13/04/2011	1	68.59	1.61	7.66	2.90	10.42	3.69	2.26	1.30	2.66	1.73	102.82
13/04/2011	2	67.44	1.83	7.40	2.84	10.87	3.70	2.37	1.18	2.58	1.58	101.79
13/04/2011	3	65.59	1.35	7.02	2.35	10.17	3.39	2.41	1.17	2.82	1.71	97.97
13/04/2011	4	67.00	1.76	7.46	2.84	11.24	3.64	2.48	1.29	2.72	1.76	102.21
13/04/2011	5	67.05	1.70	7.34	2.80	11.29	3.51	2.47	1.28	2.50	1.67	101.61
13/04/2011	6	66.21	1.74	7.30	2.86	10.92	3.57	2.30	1.33	2.73	1.72	100.67
14/04/2011	1	66.29	1.58	7.39	2.56	10.23	3.55	2.16	1.22	2.55	1.70	99.22
14/04/2011	2	66.37	1.69	7.45	2.64	10.55	3.52	2.37	1.28	2.48	1.93	100.29
14/04/2011	3	67.02	1.36	7.09	2.70	10.10	3.47	2.33	1.10	2.66	1.86	99.68
14/04/2011	4	67.90	1.63	7.52	2.69	10.61	3.66	2.23	1.35	2.70	1.56	101.85
14/04/2011	5	67.12	1.72	7.39	2.61	10.58	3.70	2.40	1.15	2.61	1.50	100.77
14/04/2011	6	64.58	1.53	6.99	2.49	10.46	3.44	2.28	1.39	2.19	1.90	97.27

Date	Point	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	Total
15/04/2011	1	66.41	1.63	7.41	2.56	10.79	3.57	1.96	1.39	2.56	1.64	99.92
15/04/2011	2	65.47	1.55	7.20	2.53	10.84	3.61	2.08	1.17	2.64	1.52	98.63
15/04/2011	3	68.20	1.70	7.56	2.79	11.00	3.68	2.24	1.38	2.44	1.78	102.78
15/04/2011	4	68.07	1.30	7.20	2.54	10.90	3.56	2.15	1.15	2.91	1.63	101.39
15/04/2011	5	66.82	1.38	7.50	2.43	10.34	3.53	2.18	1.43	2.67	1.71	99.99
15/04/2011	6	67.10	1.70	7.52	2.77	10.57	3.67	2.41	1.33	2.58	1.97	101.62
18/04/2011	1	66.74	1.37	7.21	2.48	11.89	3.48	2.33	1.25	2.71	1.63	101.10
18/04/2011	2	67.22	1.76	7.49	2.87	11.77	3.77	2.28	1.20	2.70	1.65	102.70
18/04/2011	3	66.33	1.69	7.28	2.59	11.61	3.61	2.30	1.15	2.44	1.83	100.82
18/04/2011	4	67.43	1.68	7.44	2.78	11.62	3.66	2.54	1.26	2.44	1.71	102.57
18/04/2011	5	66.73	1.69	7.39	2.77	12.05	3.60	2.18	1.25	2.30	1.62	101.59
18/04/2011	6	67.22	1.77	7.35	2.79	12.25	3.68	2.24	1.22	2.68	1.68	102.90
21/04/2011	1	67.66	1.50	7.53	2.56	10.61	3.65	2.33	1.29	2.55	1.66	101.47

Date	Point	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	Total
21/04/2011	2	66.31	1.65	7.29	2.61	10.15	3.68	2.34	1.17	2.59	1.88	99.67
21/04/2011	3	67.13	1.62	7.36	2.56	10.82	3.67	2.41	1.38	2.72	1.73	101.41
21/04/2011	4	66.43	1.55	7.29	2.56	10.63	3.67	2.12	1.35	2.77	1.60	99.95
21/04/2011	5	67.16	1.45	7.44	2.62	11.23	3.69	2.36	1.15	2.51	1.63	102.05
21/04/2011	6	65.58	1.63	7.36	2.69	10.69	3.67	2.35	1.17	2.49	1.69	99.32
22/04/2011	1	65.85	1.56	7.36	2.66	10.42	3.58	2.36	1.27	2.56	1.69	99.30
22/04/2011	2	66.84	1.63	7.66	2.67	11.40	3.71	2.35	1.26	2.53	1.74	101.81
22/04/2011	3	64.56	1.54	7.24	2.50	11.06	3.55	2.36	1.28	2.43	1.84	98.37
22/04/2011	4	65.97	1.56	7.58	2.72	10.61	3.72	2.31	1.24	2.45	1.78	99.97
22/04/2011	5	66.45	1.56	7.56	2.56	10.98	3.75	2.41	1.54	2.53	1.62	100.98
22/04/2011	6	64.99	1.54	7.31	2.49	11.04	3.48	2.39	1.39	2.52	1.62	98.76
25/04/2011	1	66.37	1.70	7.36	2.79	10.83	3.64	2.32	1.19	2.49	1.69	100.39
25/04/2011	2	66.82	1.47	7.38	2.58	10.47	3.60	2.17	1.15	2.32	1.58	99.55

Date	Point	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	Total
25/04/2011	3	66.40	1.62	7.18	2.49	10.57	3.67	2.45	1.35	2.55	1.87	100.16
25/04/2011	4	63.66	1.51	7.13	2.64	10.50	3.45	2.56	1.31	2.62	1.68	97.06
25/04/2011	5	64.42	1.60	7.06	2.65	10.62	3.50	2.38	1.22	2.28	1.71	97.42
25/04/2011	6	66.26	1.39	7.27	2.49	10.44	3.57	2.57	1.21	2.75	1.92	98.85
26/04/2011	1	65.66	1.19	7.00	2.35	10.42	3.43	2.17	1.12	2.34	1.66	97.35
26/04/2011	2	66.42	1.56	7.36	2.51	10.91	3.67	2.63	1.24	2.61	1.56	100.47
26/04/2011	3	65.78	1.56	7.40	2.58	10.82	3.63	2.22	1.86	2.51	1.65	100.00
26/04/2011	4	67.80	1.60	7.64	2.66	11.21	3.69	2.38	1.18	2.41	1.74	102.30
26/04/2011	5	65.82	1.77	7.35	2.75	11.09	3.60	2.28	1.20	2.60	1.72	100.18
26/04/2011	6	65.28	1.14	7.05	2.17	10.65	3.46	2.38	1.19	2.65	1.67	97.65
29/04/2011	1	64.27	1.50	7.07	2.65	11.04	3.48	2.19	1.19	2.45	1.72	97.57
29/04/2011	2	64.01	1.79	7.11	2.81	10.94	3.53	2.05	1.17	2.48	1.62	97.51
29/04/2011	3	66.17	1.54	7.32	2.81	10.59	3.60	1.82	1.39	2.24	1.71	99.17

Date	Point	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	Total
29/04/2011	4	66.69	1.47	7.17	2.77	11.61	3.67	2.14	1.24	2.68	1.61	101.06
29/04/2011	5	67.17	1.57	7.48	2.71	11.68	3.63	2.09	1.25	2.54	1.58	101.70
29/04/2011	6	65.39	1.67	7.32	2.58	11.16	3.58	2.35	1.36	2.59	1.63	99.63
30/04/2011	1	65.78	1.67	7.31	2.68	11.36	3.58	2.19	1.26	2.73	1.63	100.18
30/04/2011	2	66.36	1.30	7.22	2.38	11.31	3.46	2.36	1.26	2.57	1.68	99.91
30/04/2011	3	64.51	1.51	7.14	2.56	11.09	3.53	1.99	1.18	2.49	1.60	97.60
30/04/2011	4	65.30	1.42	7.27	2.62	10.71	3.44	2.09	1.16	2.65	1.68	98.35
30/04/2011	5	67.45	1.58	7.32	2.71	10.86	3.61	2.22	1.45	2.62	1.96	101.79
30/04/2011	6	66.78	1.76	7.25	2.87	10.80	3.65	2.62	1.29	2.64	1.89	101.58
16/05/2011	1	65.71	1.64	7.04	2.75	11.44	3.25	2.49	1.12	2.44	1.74	99.62
16/05/2011	2	66.69	1.54	7.31	2.56	11.21	3.50	2.30	1.25	2.71	1.64	100.72
16/05/2011	3	67.32	1.79	7.48	2.97	12.03	3.59	2.25	1.32	2.41	1.76	102.92
16/05/2011	4	64.36	1.47	7.16	2.46	11.28	3.44	2.39	1.31	2.42	1.68	97.97

Date	Point	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	Total
16/05/2011	5	66.20	1.66	7.38	2.82	11.55	3.49	2.12	1.19	2.43	1.80	100.65
16/05/2011	6	64.77	1.19	7.11	2.29	11.21	3.30	2.29	1.28	2.82	1.69	97.96
17/05/2011	1	65.64	1.31	6.98	2.42	10.88	3.37	2.41	1.26	2.14	1.86	98.26
17/05/2011	2	65.01	1.56	7.18	2.66	11.32	3.43	2.28	1.17	2.44	1.90	98.94
17/05/2011	3	66.04	1.51	7.30	2.51	11.35	3.50	2.36	1.30	2.49	1.50	99.87
17/05/2011	4	67.39	1.86	7.47	3.04	11.62	3.48	2.40	1.21	2.53	1.63	102.63
17/05/2011	5	65.40	1.33	7.04	2.41	11.29	3.37	2.36	1.26	2.44	1.45	98.33
17/05/2011	6	66.81	1.30	7.24	2.45	11.08	3.33	2.02	1.26	2.17	1.69	99.35
18/05/2011	1	64.77	1.56	7.19	2.58	10.38	3.43	2.26	1.29	2.90	1.54	97.90
18/05/2011	2	64.32	1.74	7.40	2.64	10.68	3.55	2.24	1.27	2.25	1.83	97.92
18/05/2011	3	64.66	1.58	7.25	2.55	10.62	3.43	2.23	1.25	2.32	1.74	97.63
18/05/2011	4	65.25	1.75	7.35	2.76	11.05	3.44	2.19	1.35	2.40	1.62	99.16
18/05/2011	5	64.66	1.79	7.28	2.87	10.91	3.51	2.13	1.35	2.31	1.56	98.39

Date	Point	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	Total
18/05/2011	6	65.14	1.63	7.57	2.65	10.63	3.52	2.22	1.36	2.68	1.85	99.23
28/05/2011	1	67.01	1.52	7.64	2.56	10.29	3.66	2.26	1.38	2.53	1.76	100.61
28/05/2011	2	66.09	1.55	7.24	2.60	10.83	3.45	2.45	1.30	2.64	1.78	99.92
28/05/2011	3	65.78	1.61	7.28	2.70	11.05	3.56	2.22	1.31	2.30	1.69	99.49
28/05/2011	4	67.71	1.25	7.44	2.28	11.44	3.63	2.38	1.09	2.54	1.78	101.54
28/05/2011	5	65.31	1.79	7.32	2.94	10.75	3.39	2.17	1.37	2.50	1.69	99.24
28/05/2011	6	65.28	1.37	7.16	2.43	11.01	3.30	2.32	1.13	2.38	1.70	98.09
29/05/2011	1	66.31	1.59	7.60	2.68	10.29	3.54	2.20	1.37	2.36	1.89	99.83
29/05/2011	2	66.18	1.51	7.58	2.55	10.04	3.55	1.87	1.36	2.22	1.76	98.62
29/05/2011	3	64.31	1.66	7.44	2.80	10.04	3.49	2.36	1.27	2.49	1.57	97.43
29/05/2011	4	65.30	1.51	7.45	2.55	10.00	3.54	2.20	1.19	2.69	1.74	98.16
29/05/2011	5	65.25	1.65	7.46	2.62	10.39	3.57	2.28	1.15	2.21	1.83	98.42
29/05/2011	6	68.33	1.60	7.58	2.79	10.60	3.76	2.55	1.25	2.58	1.72	102.76

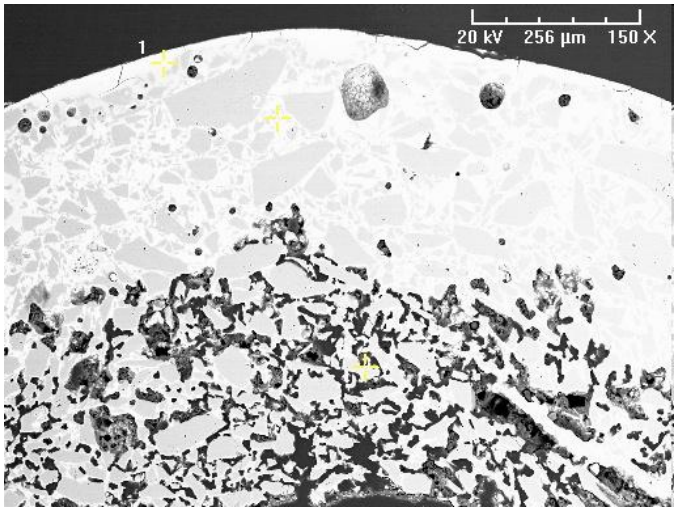
Date	Point	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	Total
14/07/2011	1	66.65	1.24	7.57	2.16	10.31	3.48	2.15	1.32	2.66	1.74	99.28
14/07/2011	2	66.58	1.77	7.72	2.86	10.57	3.72	2.41	1.26	2.01	1.81	100.70
14/07/2011	3	66.28	1.73	7.51	2.74	10.40	3.69	2.34	1.28	2.65	1.66	100.28
14/07/2011	4	66.51	1.64	7.70	2.61	10.39	3.67	2.18	1.20	2.75	1.60	100.27
14/07/2011	5	65.00	1.66	7.44	2.63	10.43	3.68	2.34	1.39	2.58	1.71	98.86
14/07/2011	6	64.04	1.70	7.87	2.67	10.78	3.62	2.21	1.25	2.34	1.82	100.42
15/07/2011	1	67.45	1.74	8.01	2.60	10.19	3.66	2.32	1.51	2.50	1.66	101.95
15/07/2011	2	66.71	1.75	7.77	2.77	10.21	3.69	2.40	1.41	2.58	1.57	100.85
15/07/2011	3	68.47	1.28	7.81	2.19	10.23	3.64	2.53	1.20	2.28	1.81	101.44
15/07/2011	4	66.76	1.59	7.38	2.50	10.39	3.41	1.97	1.19	2.58	1.74	99.51
15/07/2011	5	68.39	1.62	7.89	2.45	10.20	3.71	2.41	1.41	2.61	1.79	102.49
15/07/2011	6	66.48	1.63	7.70	2.80	11.20	3.73	2.43	1.41	2.82	1.88	102.07
08/09/2011	1	66.97	1.86	8.27	2.81	10.53	4.02	2.52	1.56	2.76	1.68	102.97

Date	Point	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	Total
08/09/2011	2	63.21	1.71	7.85	2.79	10.03	3.78	2.37	1.21	2.52	1.80	97.26
08/09/2011	3	64.68	1.89	8.05	2.92	10.80	3.85	2.39	1.33	2.56	1.59	100.07
08/09/2011	4	63.81	1.87	8.10	2.86	10.22	3.88	2.38	1.37	2.40	1.76	98.64
08/09/2011	5	62.61	1.89	7.79	2.66	10.40	3.77	2.44	1.36	2.39	1.76	97.07
08/09/2011	6	63.77	1.72	8.13	2.63	10.21	3.77	2.26	1.38	2.77	1.79	98.43
16/05/2012	1	68.39	1.41	5.99	3.02	11.03	3.10	1.95	0.86	2.45	1.37	99.55
16/05/2012	2	68.19	1.63	5.86	3.12	11.04	3.10	1.79	0.74	2.60	1.62	99.88
16/05/2012	3	67.56	1.32	5.82	3.23	10.87	3.10	1.71	1.03	2.28	1.37	98.13
16/05/2012	4	68.15	1.53	6.00	3.06	11.20	3.18	1.83	0.98	2.97	1.29	100.36
16/05/2012	5	67.60	1.41	5.91	3.29	11.14	3.16	1.76	0.94	2.47	1.23	98.74
16/05/2012	6	67.22	1.47	5.79	2.99	10.83	3.04	1.63	0.85	2.27	1.37	97.48
19/05/2012	1	68.36	1.13	5.80	2.60	10.51	2.88	1.77	0.87	2.69	1.44	98.05
19/05/2012	2	69.73	1.15	6.20	2.70	10.83	3.16	1.77	0.80	2.55	1.49	100.39

Date	Point	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	Total
19/05/2012	3	68.70	1.65	6.25	3.34	11.48	3.22	1.64	0.85	2.49	1.15	100.77
19/05/2012	4	69.93	1.64	6.14	3.21	11.64	3.32	1.70	0.98	2.25	1.37	102.18
19/05/2012	5	67.70	1.53	5.87	3.18	11.44	3.15	1.86	0.90	2.40	1.30	99.32
19/05/2012	6	66.68	1.43	5.93	3.15	11.26	3.18	1.80	1.07	2.67	1.45	98.63
20/05/2012	1	68.02	1.62	6.02	3.27	11.90	3.26	1.52	1.12	2.55	1.27	100.54
20/05/2012	2	69.37	1.27	6.08	3.02	11.21	3.20	1.72	0.99	2.52	1.50	100.89
20/05/2012	3	66.75	1.43	6.08	3.07	11.31	3.12	1.90	0.94	2.49	1.41	98.51
20/05/2012	4	66.77	1.14	5.77	2.84	10.93	3.02	1.80	0.88	2.59	1.47	97.26
20/05/2012	5	67.68	1.56	6.39	3.19	11.24	3.15	1.84	0.93	2.78	1.42	100.18
20/05/2012	6	69.93	1.41	6.04	3.15	11.27	3.36	1.88	0.94	2.93	1.54	102.45

Appendix F: SEM Images

Garstang Museum



Firgure F.1: Profile 1 of Middle Kingdom bead 9384-1, efflorescence.

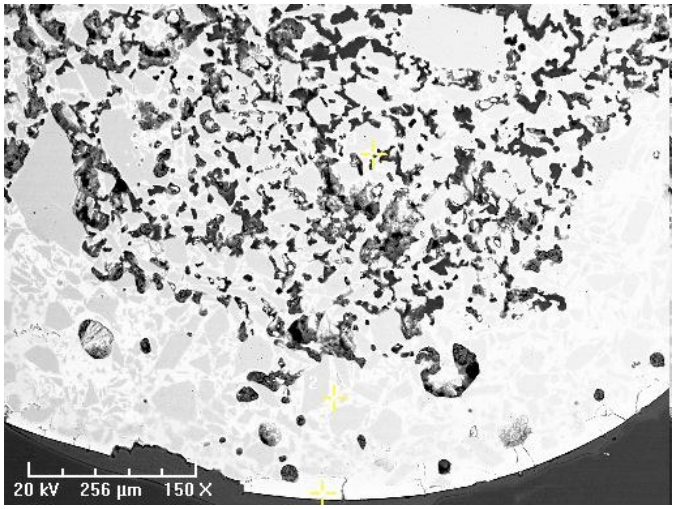


Figure F.2: Profile 2 of Middle Kingdom bead 9384-1, efflorescence.

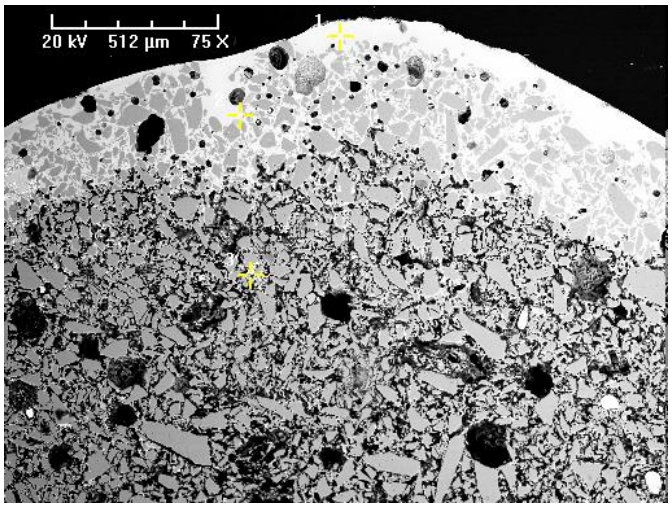


Figure F.3: Profile 1 of Middle Kingdom bead 9384-2, cementation.

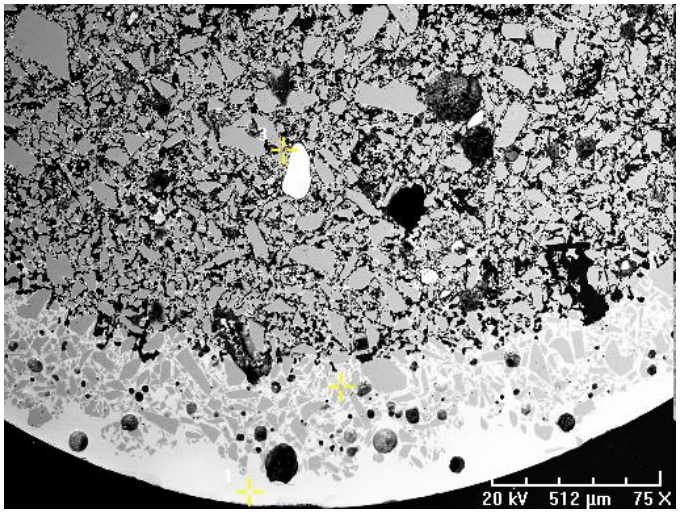


Figure F.4: Profile 2 of Middle Kingdom bead 9384-2, cementation.

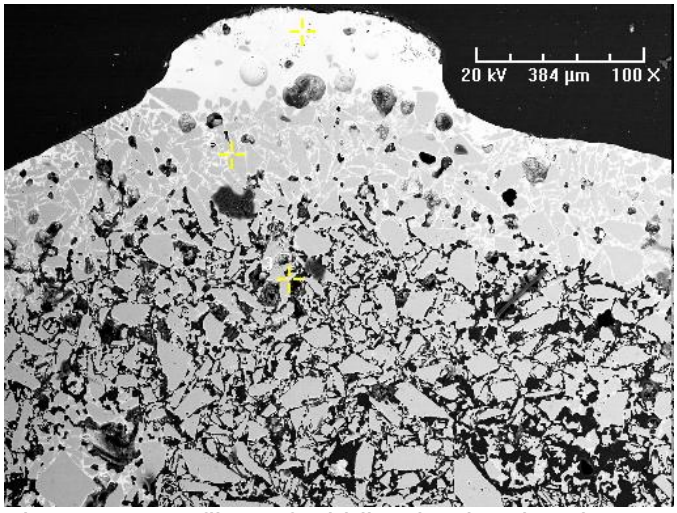


Figure F.5: Profile 1 of Middle Kingdom bead 9384-3, cementation.

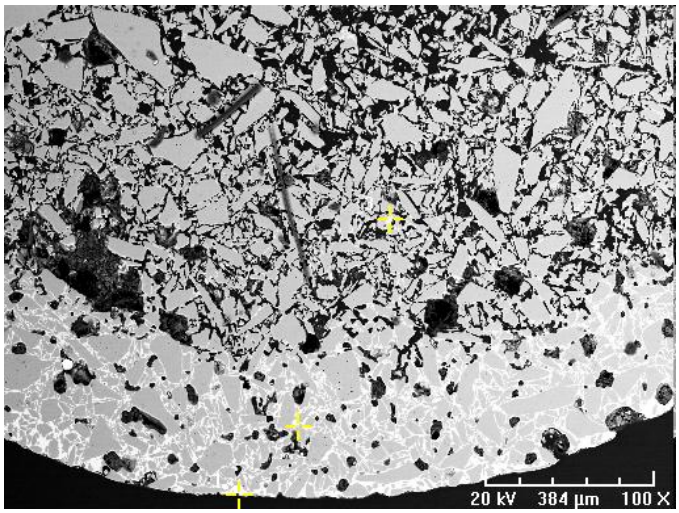


Figure F.6: Profile 2 of Middle Kingdom bead 9384-3, cementation.

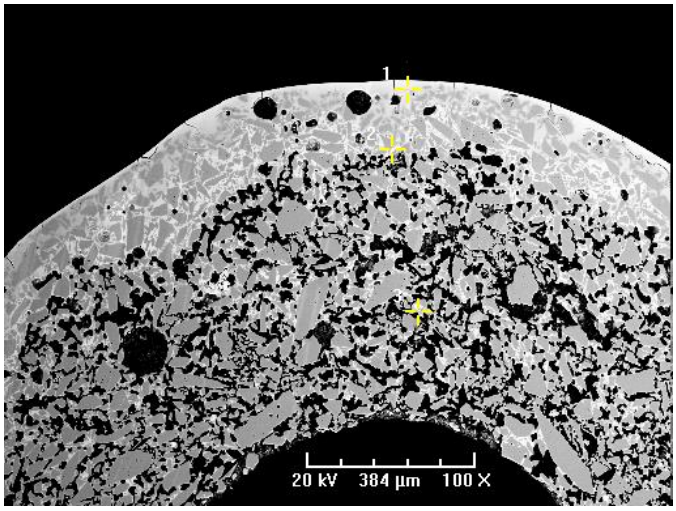


Figure F.7: Profile 1 of Middle Kingdom bead 9384-4, efflorescence.

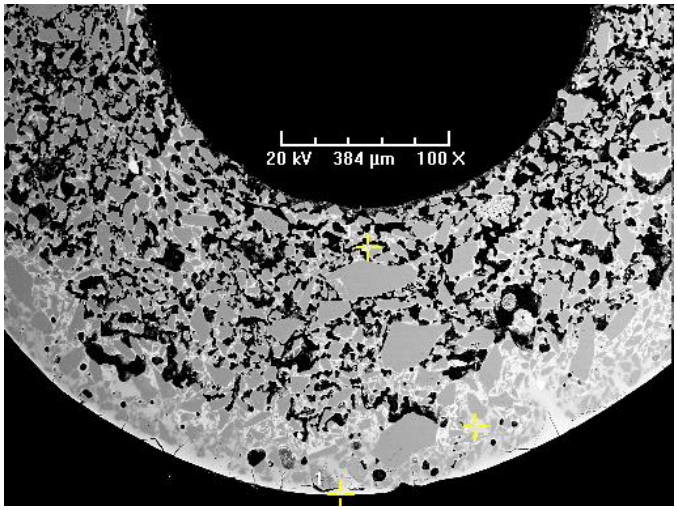


Figure F.8: Profile 2 of Middle Kingdom bead 9384-4, efflorescence.

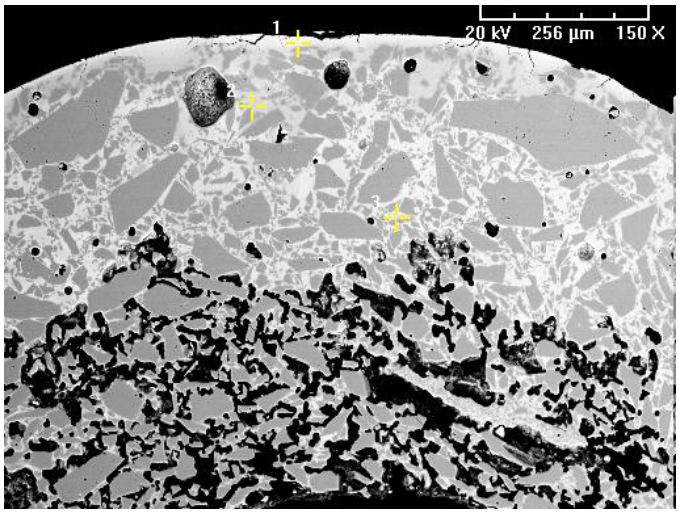


Figure F.9: Profile 1 of Middle Kingdom bead 9384-5, efflorescence.

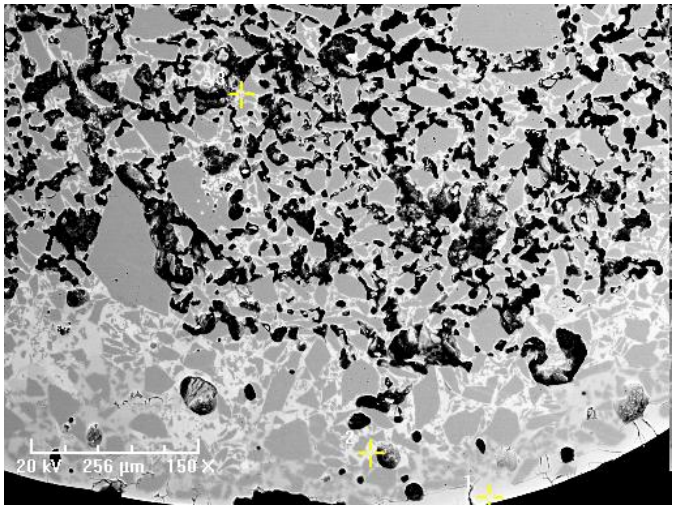


Figure F.10: Profile 2 of Middle Kingdom bead 9384-5, efflorescence.

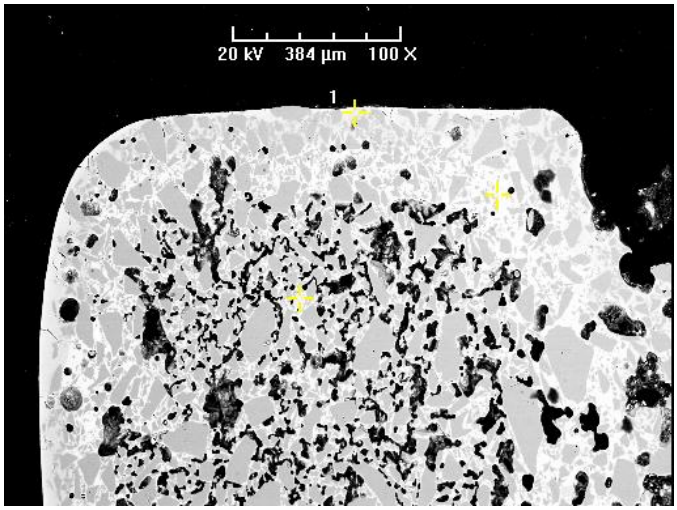


Figure F.11: Profile 1 of Middle Kingdom bead 9384-6, efflorescence.

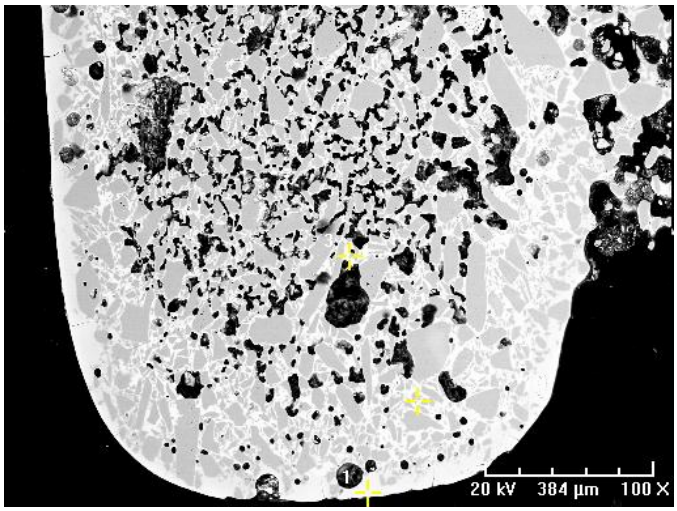


Figure F.12: Profile 2 of Middle Kingdom bead 9384-6, efflorescence.

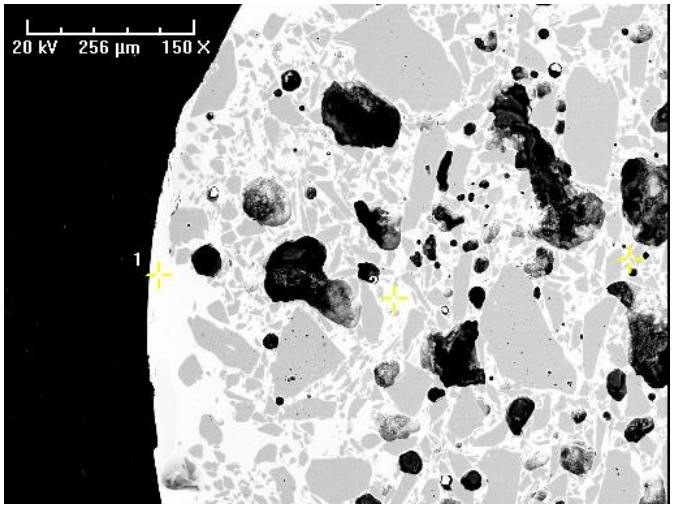


Figure F.13: Profile 1 of Middle Kingdom bead 9384-7, efflorescence.

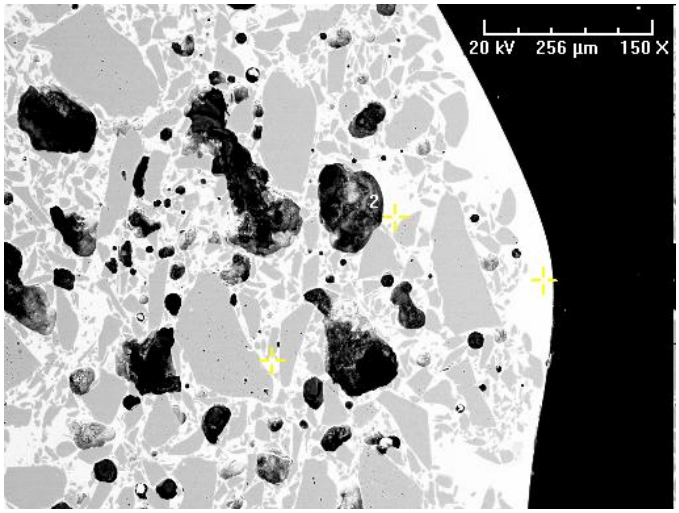


Figure F.14: Profile 2 of Middle Kingdom bead 9384-7, efflorescence.

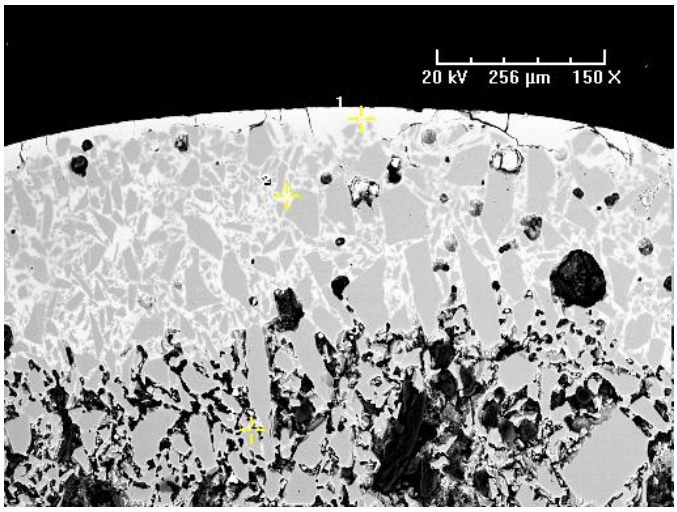


Figure F.15: Profile 1 of Middle Kingdom bead 9384-8, cementation.

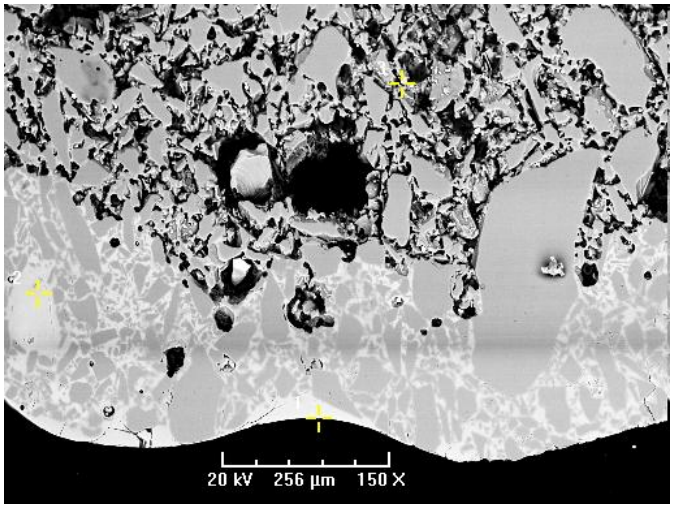


Figure F.16: Profile 2 of Middle Kingdom bead 9384-8, cementation.

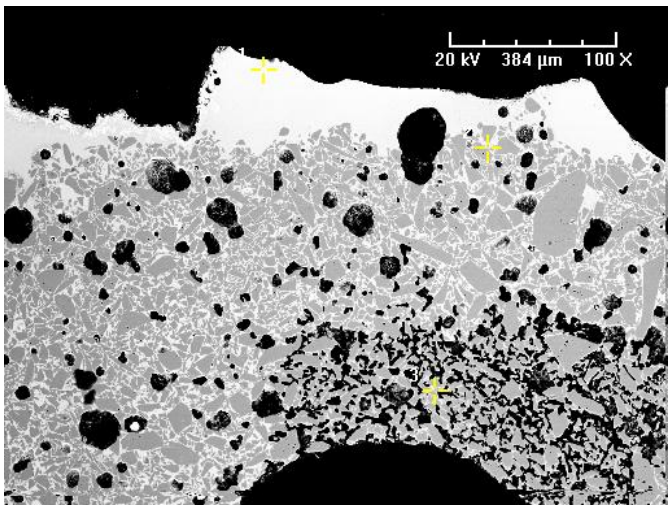


Figure F.17: Profile 1 of Middle Kingdom bead 9384-9, efflorescence.

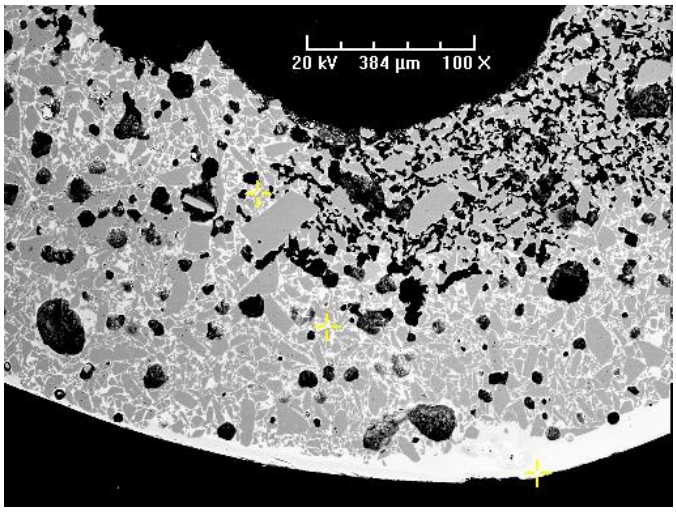


Figure F.18: Profile 2 of Middle Kingdom bead 9384-9, efflorescence.

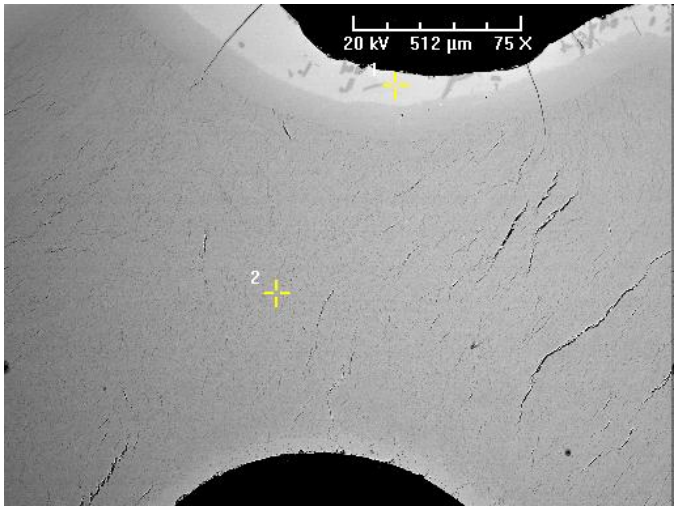


Figure F.19: Profile 1 of Middle Kingdom bead 9384-10, application glaze on stone.

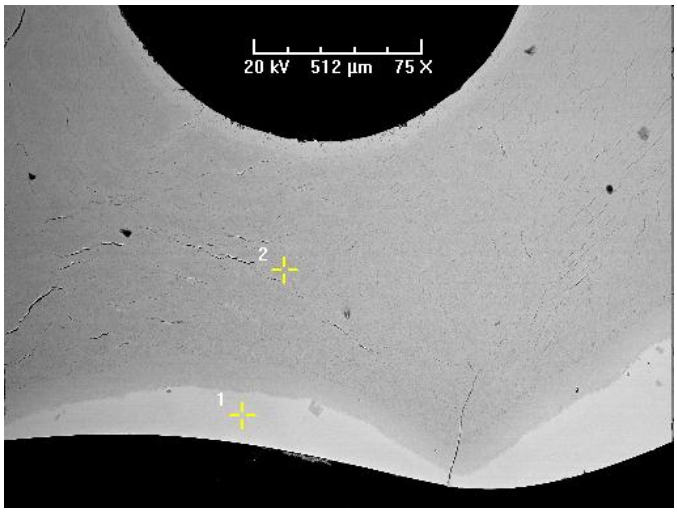


Figure F.20: Profile 2 of Middle Kingdom bead 9384-10, application glaze on stone.

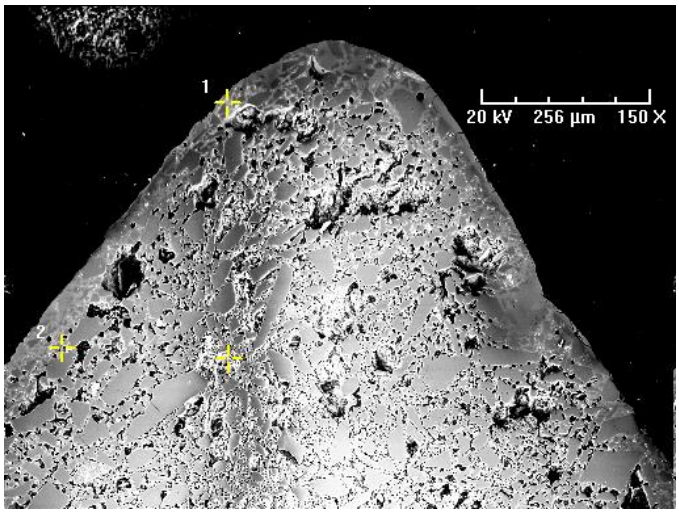


Figure F.21: Profile 1 of Middle Kingdom bead 2345-1, efflorescence.

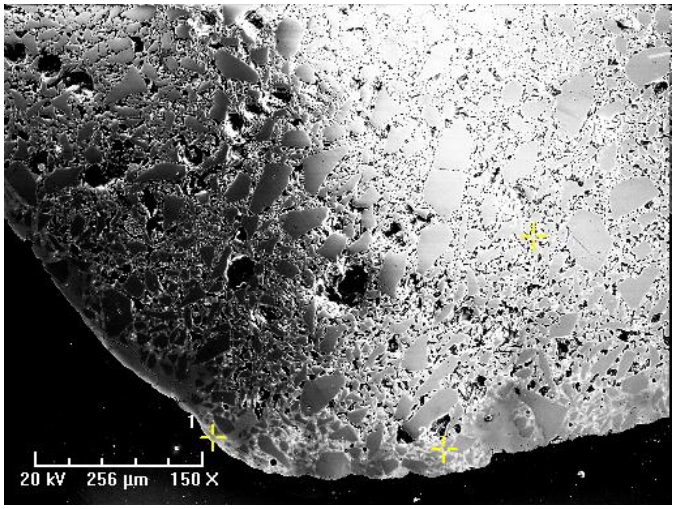


Figure F.22: Profile 2 of Middle Kingdom bead 2345-1, efflorescence.

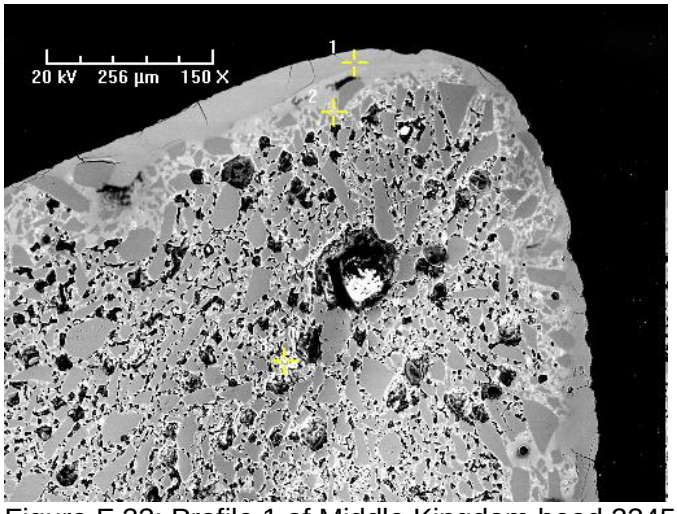


Figure F.23: Profile 1 of Middle Kingdom bead 2345-2, efflorescence.

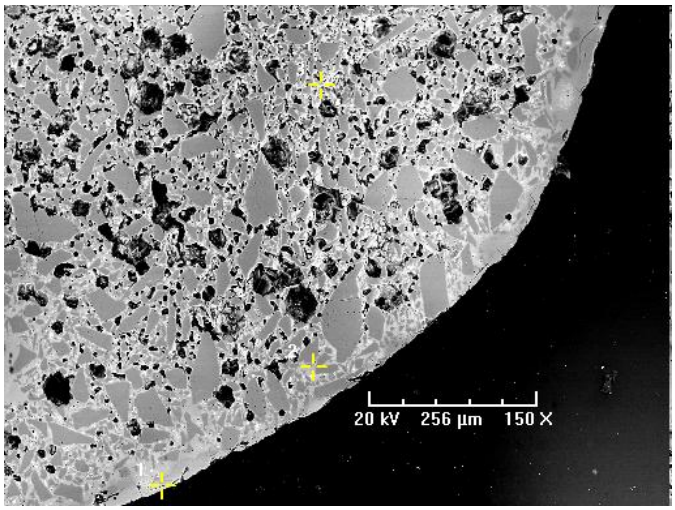


Figure F.24: Profile 2 of Middle Kingdom bead 2345-2, efflorescence.

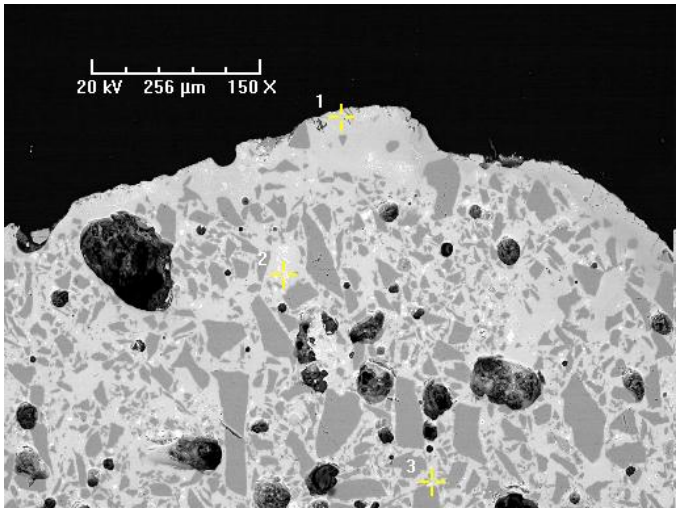


Figure F.25: Profile 1 of Middle Kingdom bead 2345-3, efflorescence.

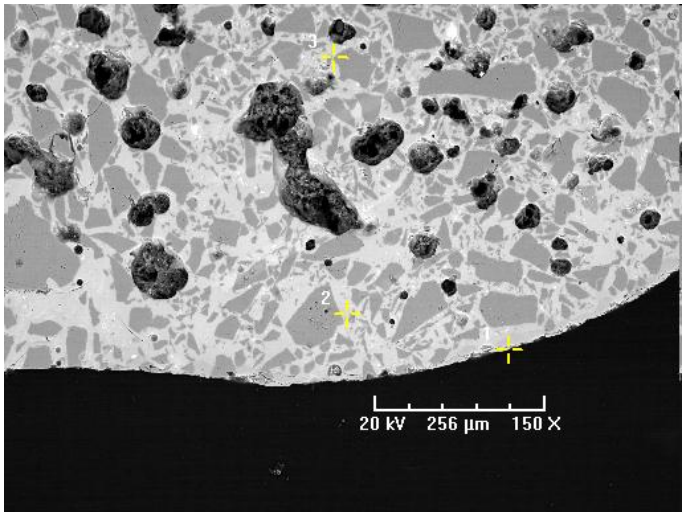


Figure F.26: Profile 2 of Middle Kingdom bead 2345-3, efflorescence.

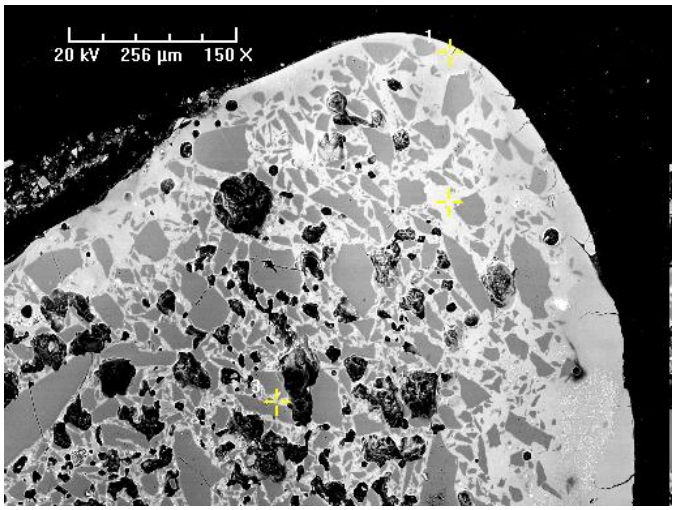


Figure F.27: Profile 1 of Middle Kingdom bead 2345-4, efflorescence.

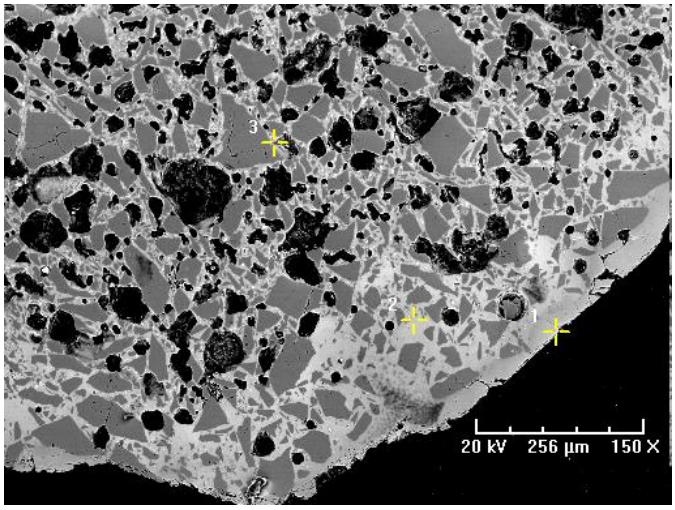


Figure F.28: Profile 2 of Middle Kingdom bead 2345-4, efflorescence.

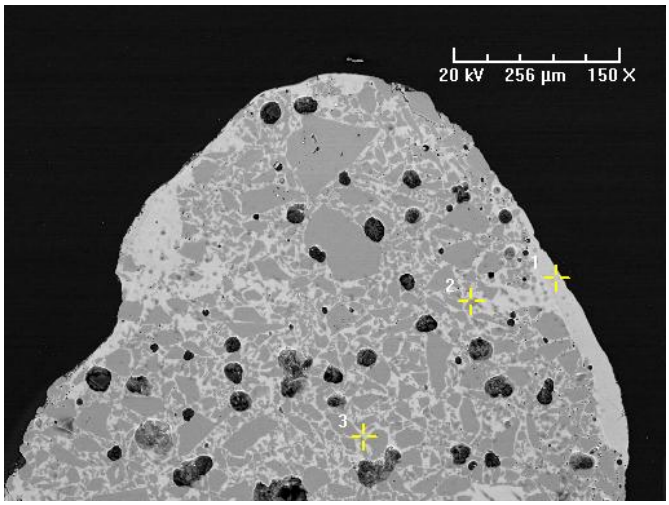


Figure F.29: Profile 1 of Middle Kingdom bead 2345-5, efflorescence.

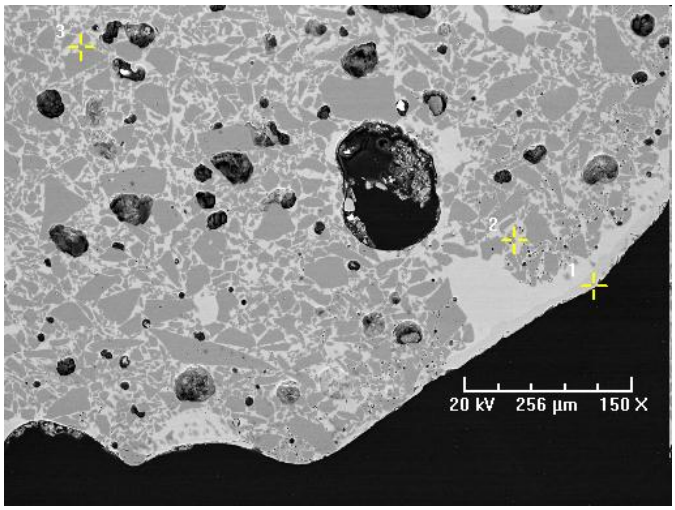


Figure F.30: Profile 2 of Middle Kingdom bead 2345-5, efflorescence.

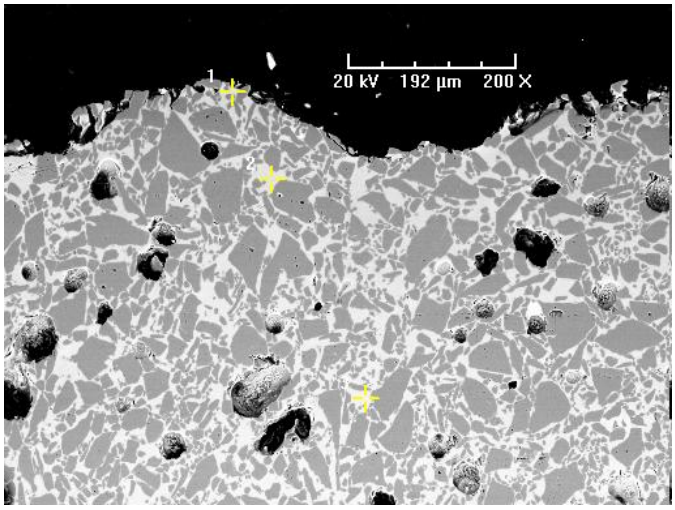


Figure F.31: Profile 1 of Middle Kingdom bead 2345-6, efflorescence.

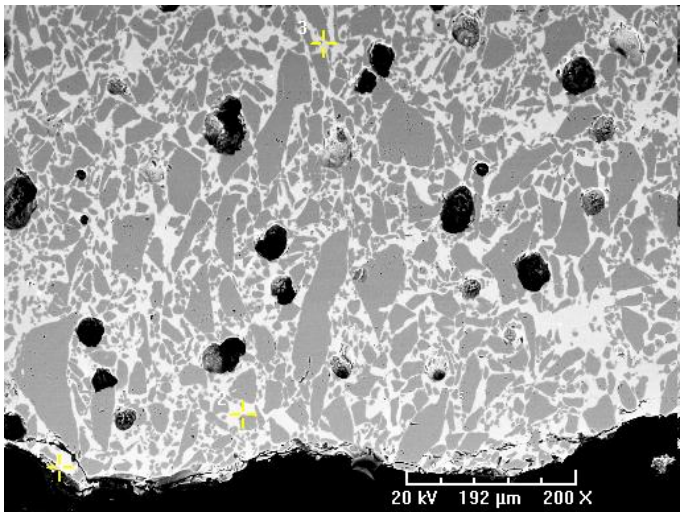


Figure F.32: Profile 2 of Middle Kingdom bead 2345-6, efflorescence.

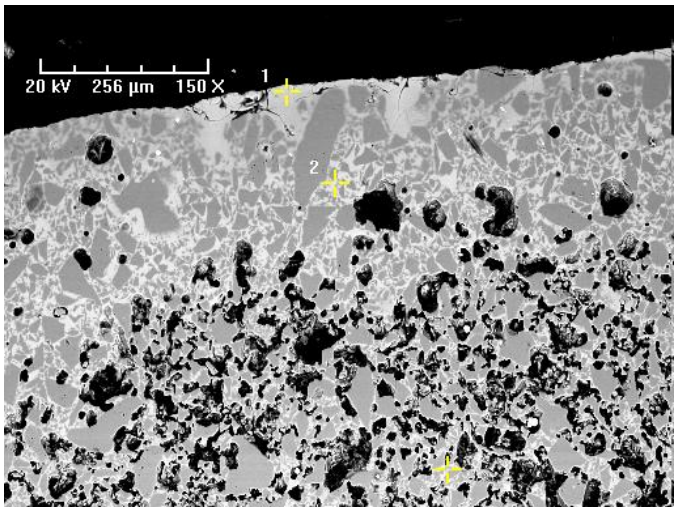


Figure F.33: Profile 1 of Middle Kingdom bead 2345-7, efflorescence.

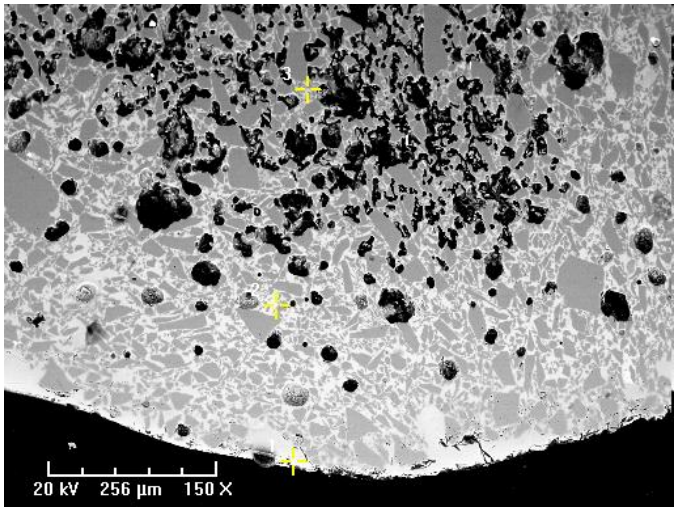


Figure F.34: Profile 2 of Middle Kingdom bead 2345-7, efflorescence.

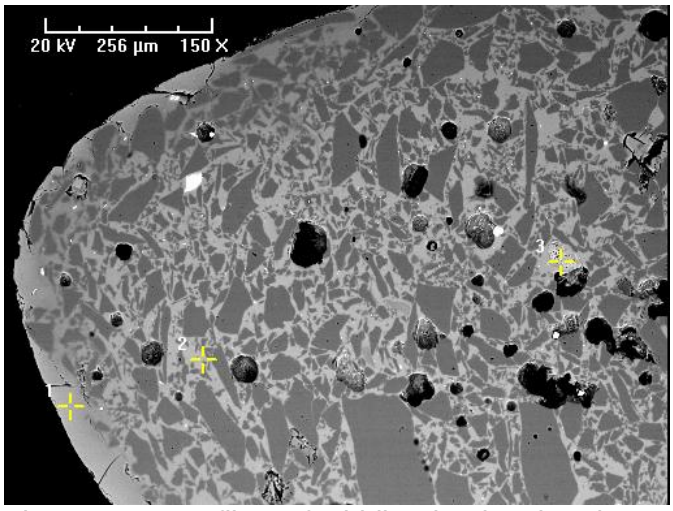


Figure F.35: Profile 1 of Middle Kingdom bead 2345-8, efflorescence.

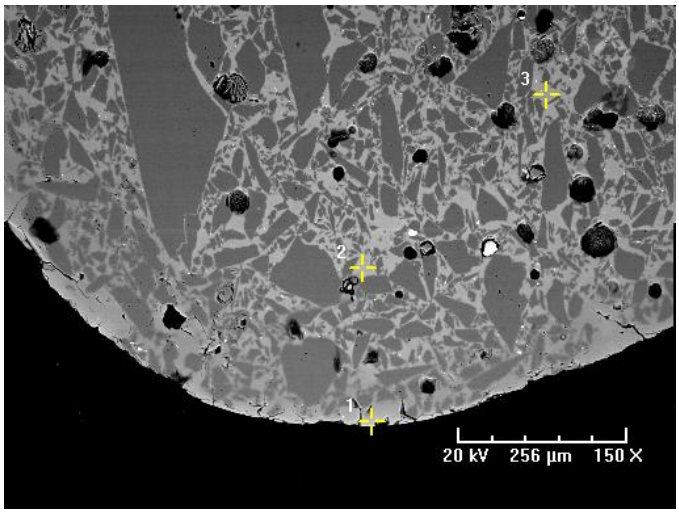


Figure F.36: Profile 2 of Middle Kingdom bead 2345-8, efflorescence.

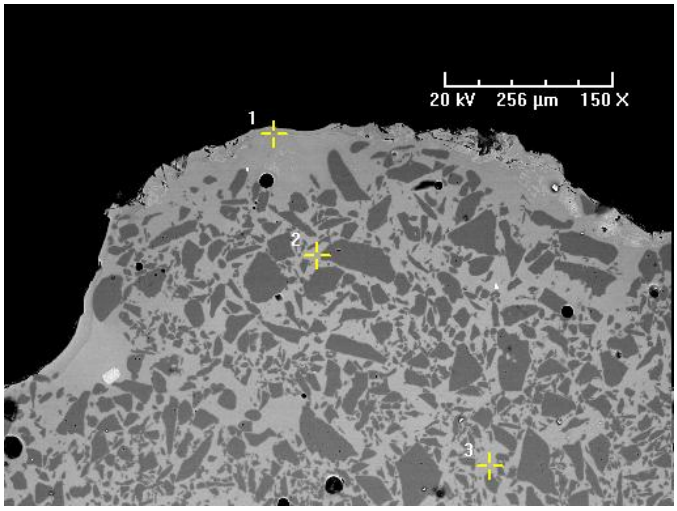


Figure F.37: Profile 1 of Middle Kingdom bead 2345-9, efflorescence.

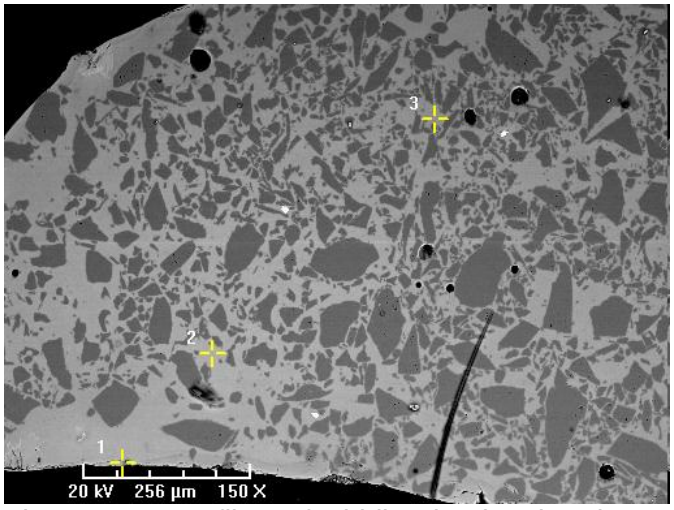


Figure F.38: Profile 2 of Middle Kingdom bead 2345-9, efflorescence.

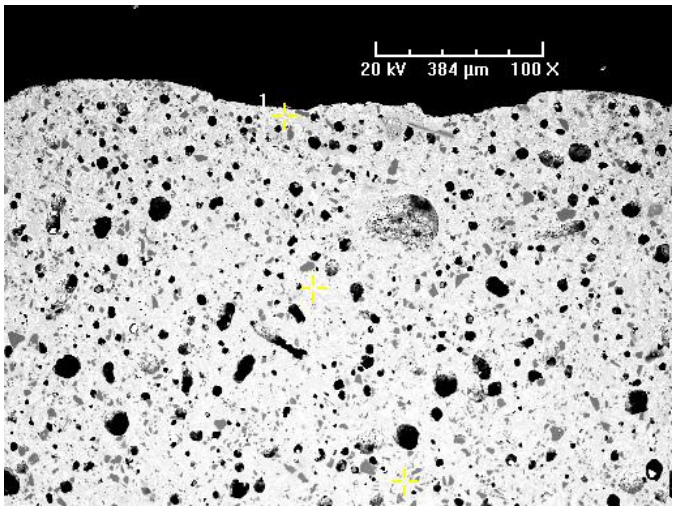


Figure F.39: Profile 1 of Middle Kingdom bead 2345-10, cementation.

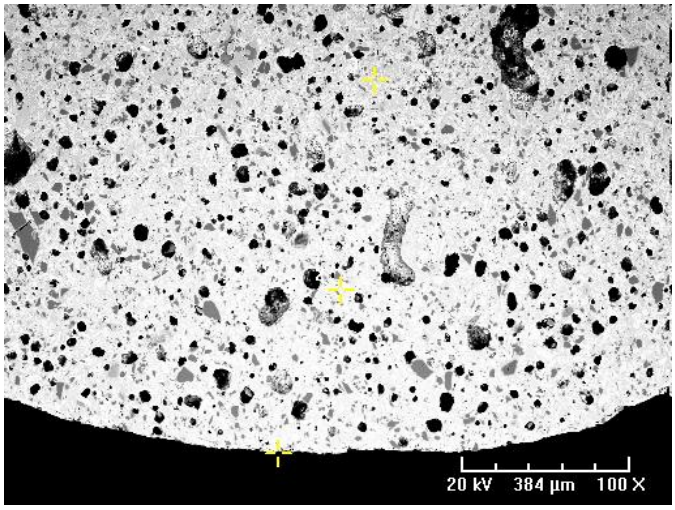


Figure F.40: Profile 2 of Middle Kingdom bead 2345-10, cementation.

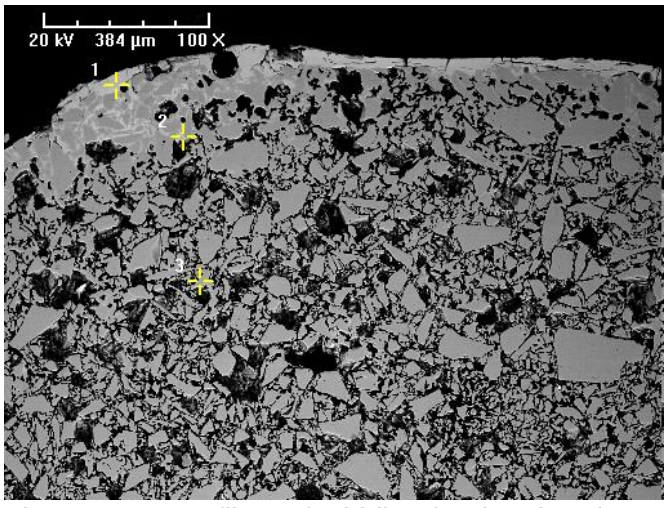


Figure F.41: Profile 1 of Middle Kingdom bead 2379-1, cementation.

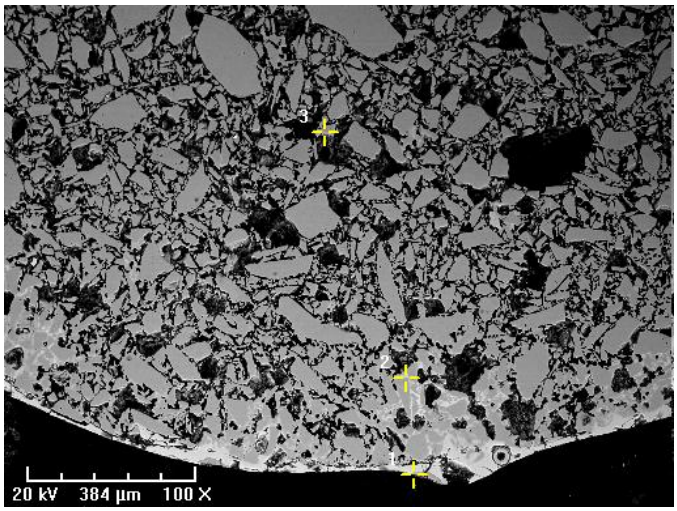


Figure F.42: Profile 2 of Middle Kingdom bead 2379-1, cementation.

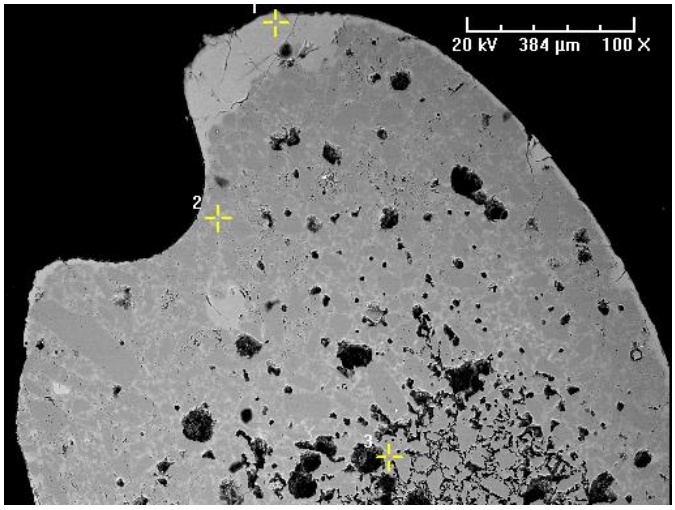


Figure F.43: Profile 1 of Middle Kingdom bead 2379-2, cementation.

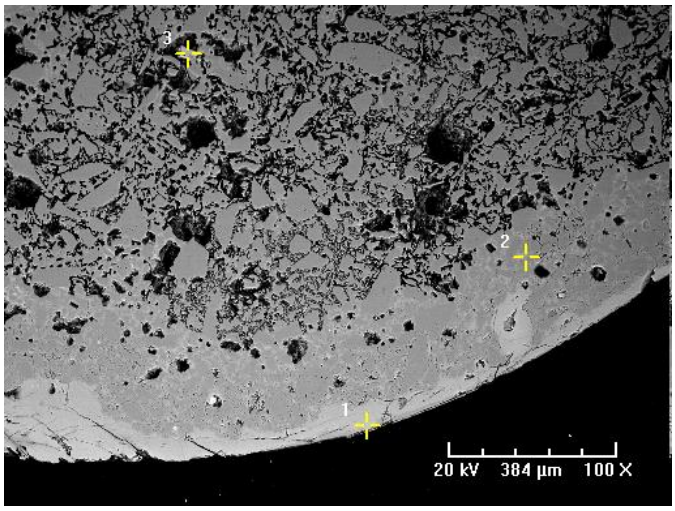


Figure F.44: Profile 2 of Middle Kingdom bead 2379-2, cementation.

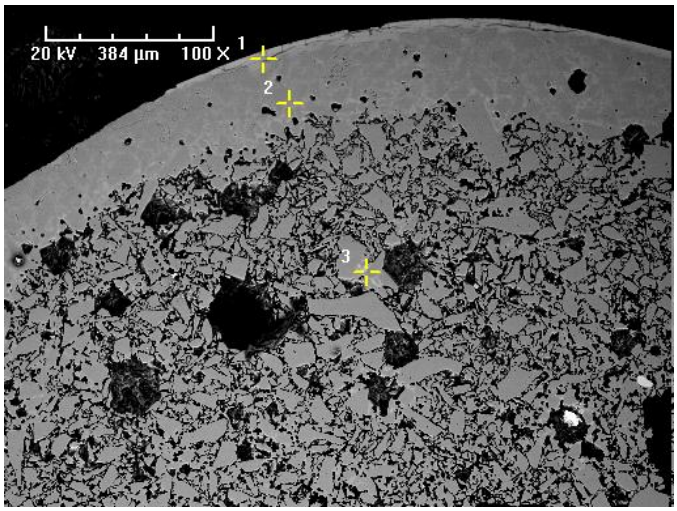


Figure F.45: Profile 1 of Middle Kingdom bead 2379-3, cementation.

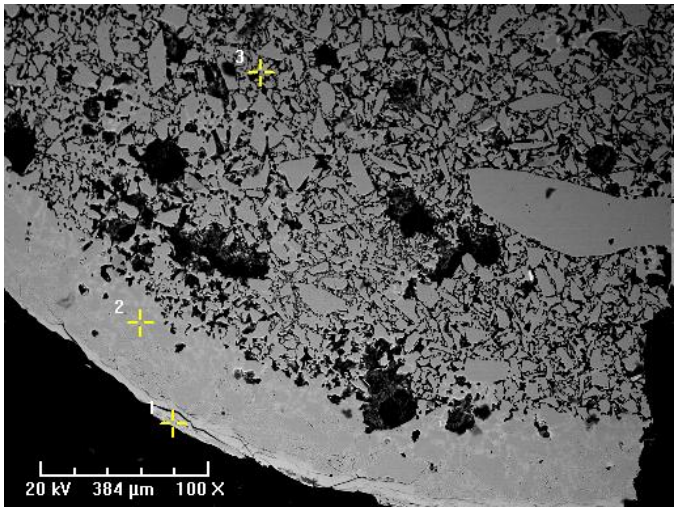


Figure F.46: Profile 2 of Middle Kingdom bead 2379-3, cementation.

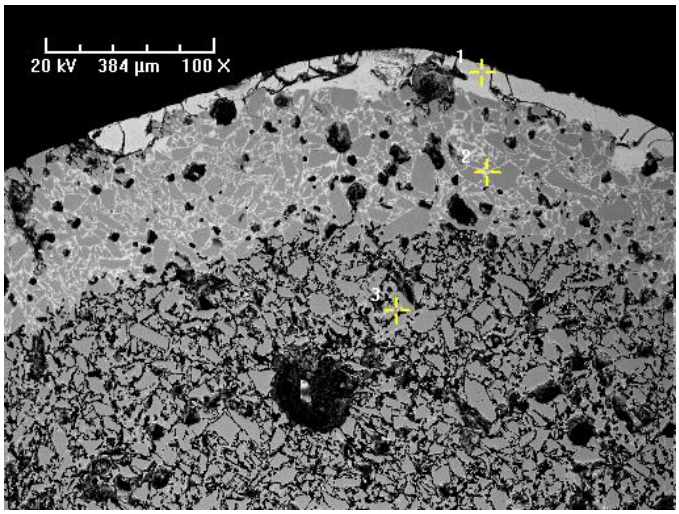


Figure F.47: Profile 1 of Middle Kingdom bead 2379-4, cementation.

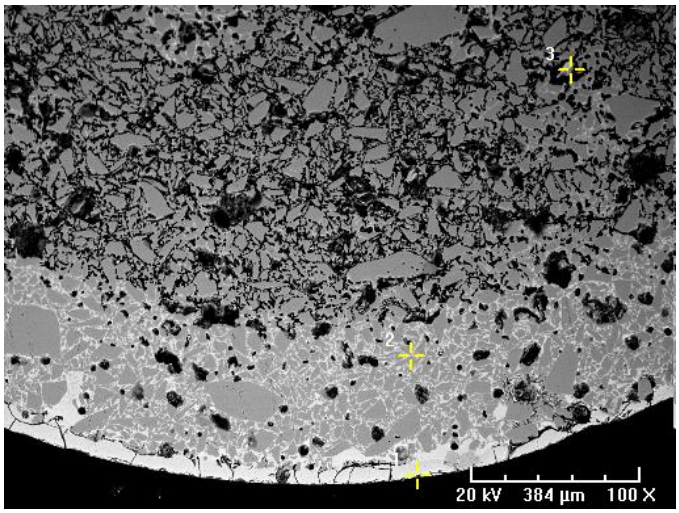


Figure F.48: Profile 2 of Middle Kingdom bead 2379-4, cementation.

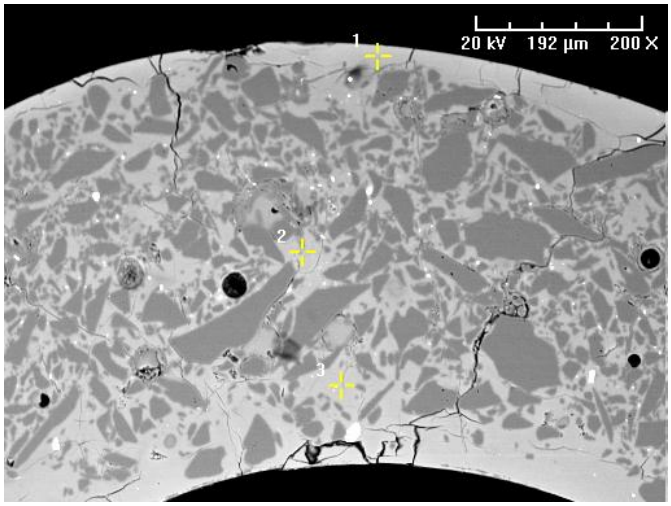


Figure F.49: Profile 1 of Middle Kingdom bead 2379-5, efflorescence.

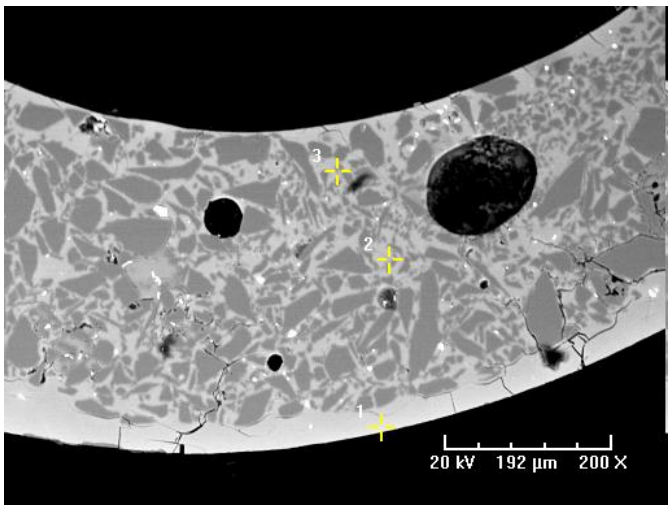


Figure F.50: Profile 2 of Middle Kingdom bead 2379-5, efflorescence.

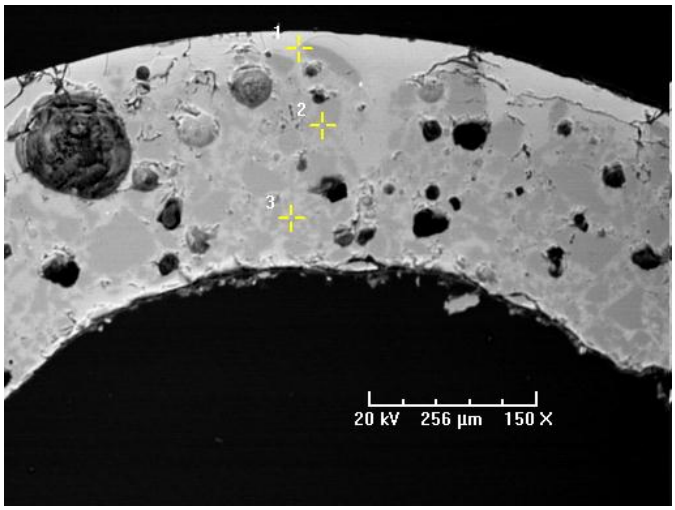


Figure F.51: Profile 1 of Middle Kingdom bead 2379-6, efflorescence.

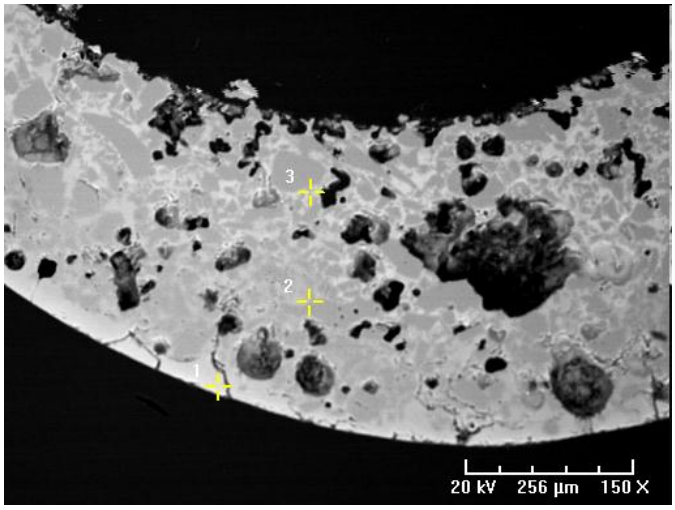


Figure F.52: Profile 2 of Middle Kingdom bead 2379-6, efflorescence.

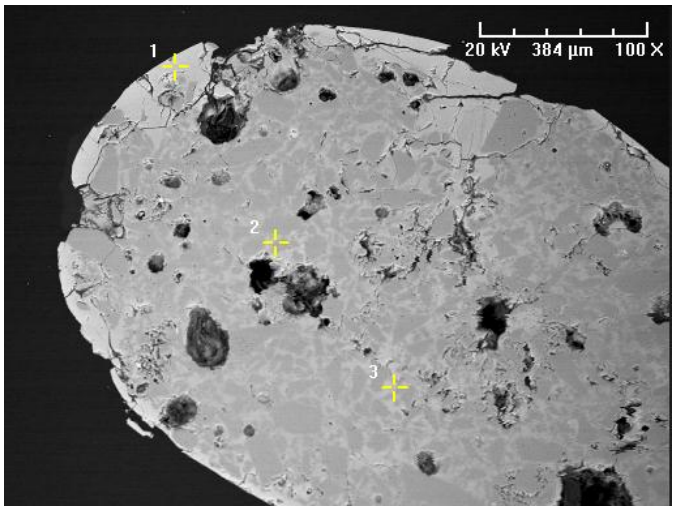


Figure F.53: Profile 1 of Middle Kingdom bead 2379-7, efflorescence.

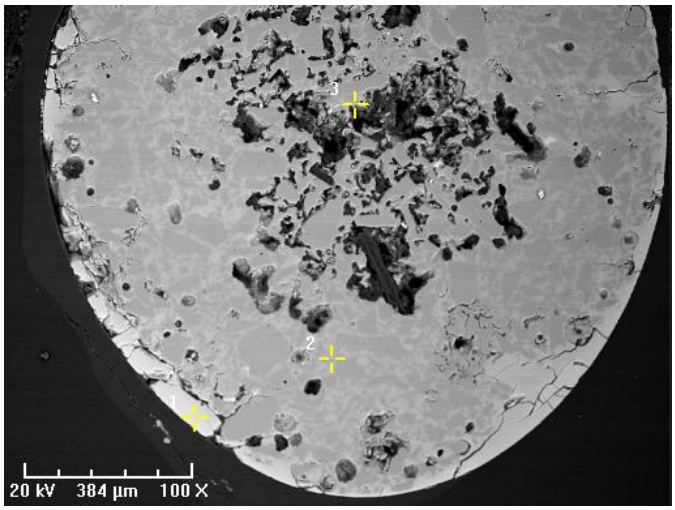


Figure F.54: Profile 2 of Middle Kingdom bead 2379-7, efflorescence.

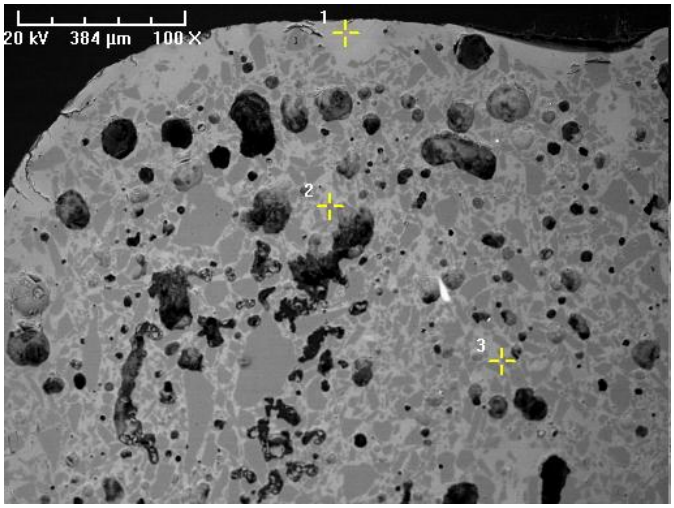


Figure F.55: Profile 1 of Middle Kingdom bead 2379-8, efflorescence.

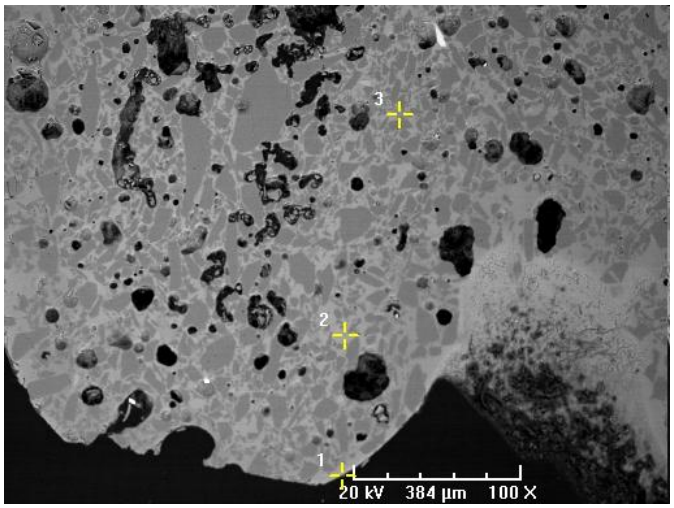


Figure F.56: Profile 2 of Middle Kingdom bead 2379-8, efflorescence.

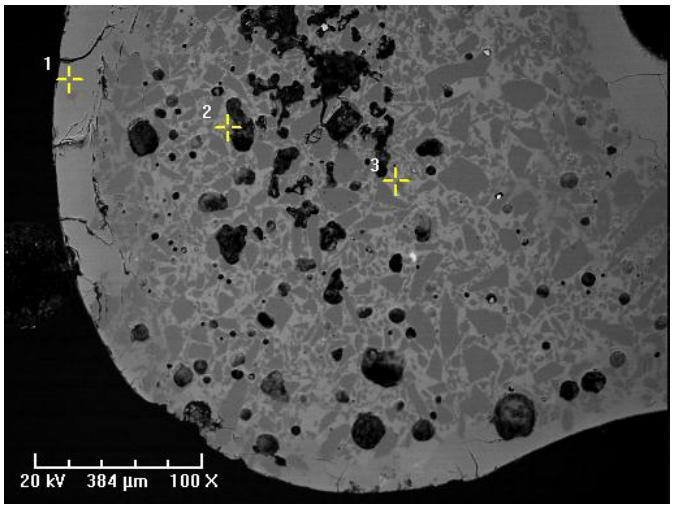


Figure F.57: Profile 1 of Middle Kingdom bead 2379-9, efflorescence.

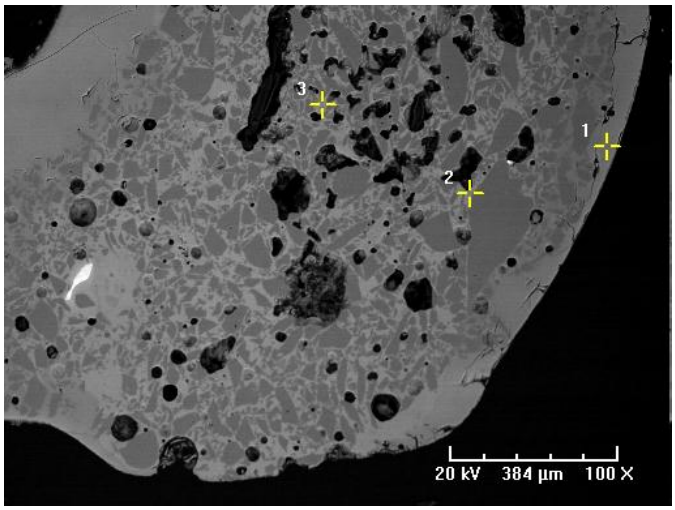


Figure F.58: Profile 2 of Middle Kingdom bead 2379-9, efflorescence.

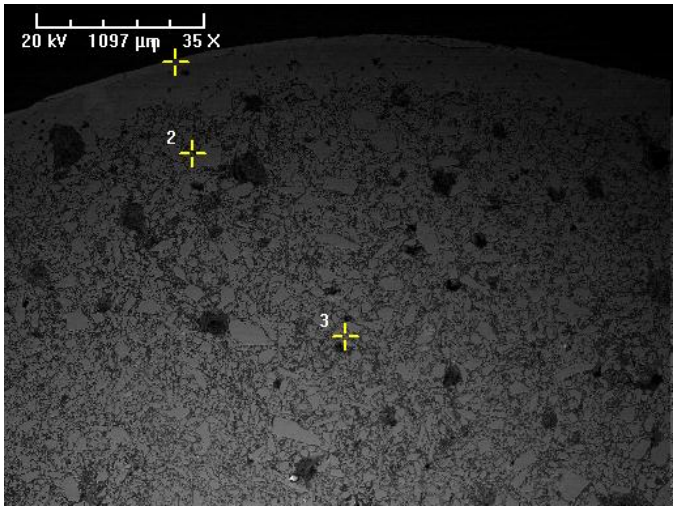


Figure F.59: Profile 1 of Middle kingdom bead 2379-10, cementation.

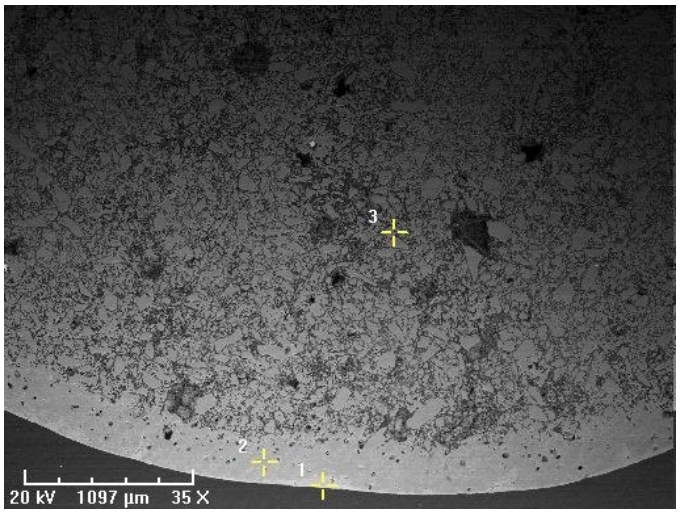


Figure F.60: Profile 2 of Middle Kingdom bead 2379-10, cementation.

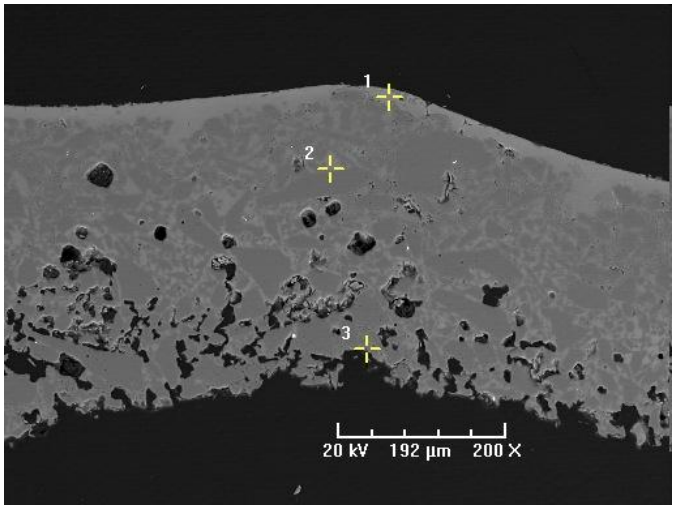


Figure F.61: Profile 1 of Middle Kingdom bead 2130-1, efflorescence.

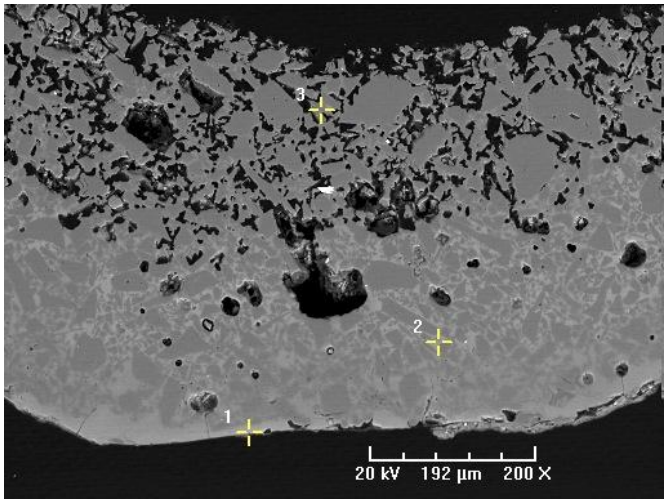


Figure F.62: Profile 2 of Middle Kingdom bead 2130-1, efflorescence.

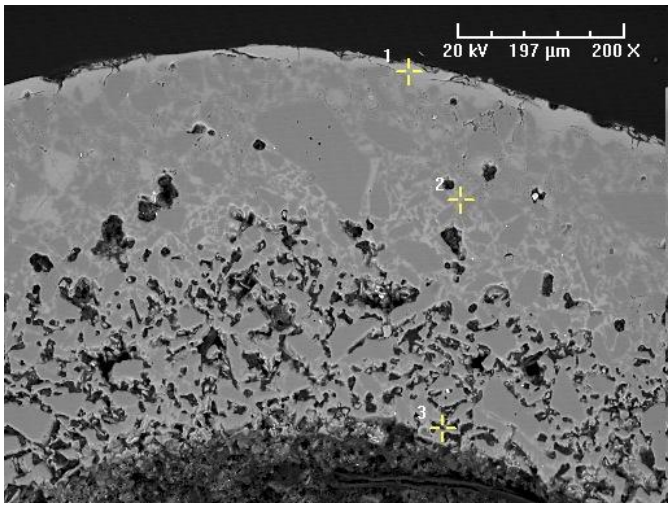


Figure F.63: Profile 1 of Middle Kingdom bead 2130-2, efflorescence.

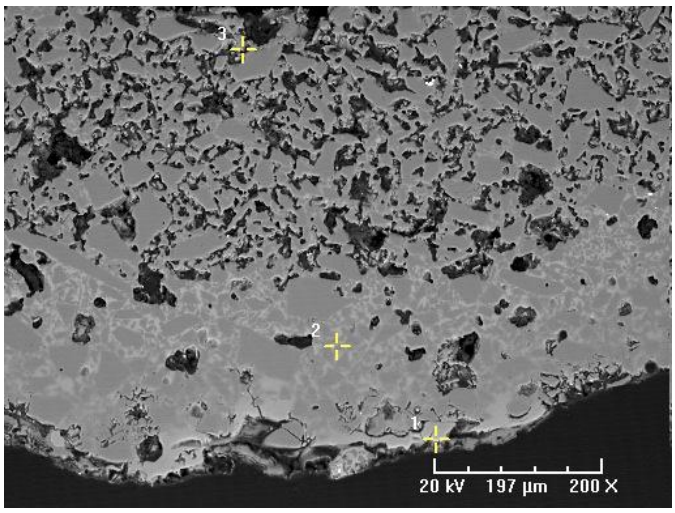


Figure F.64: Profile 2 of Middle Kingdom bead 2130-2, efflorescence.

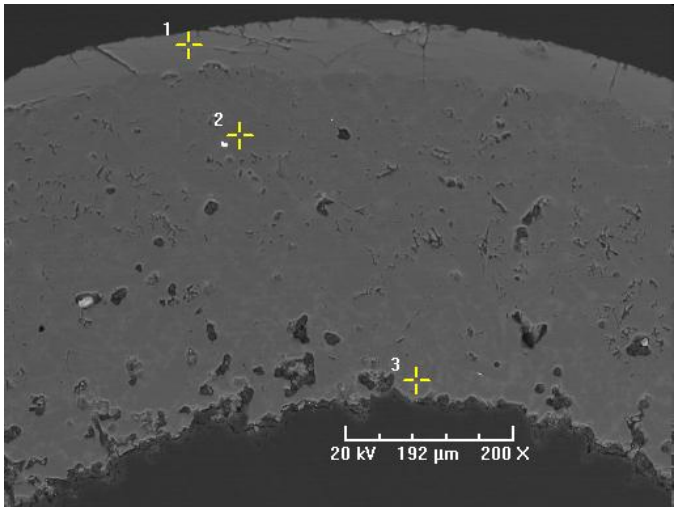


Figure F.65: Profile 1 of Middle Kingdom bead 2130-3, efflorescence.

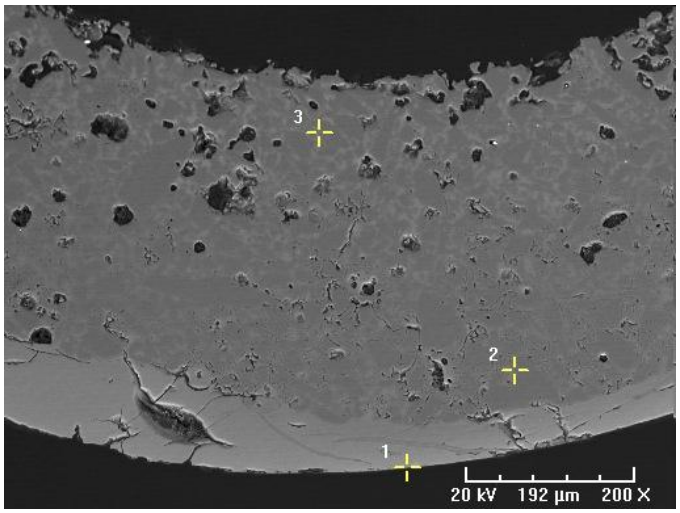


Figure F.66: Profile 2 of Middle Kingdom bead 2130-3, efflorescence.

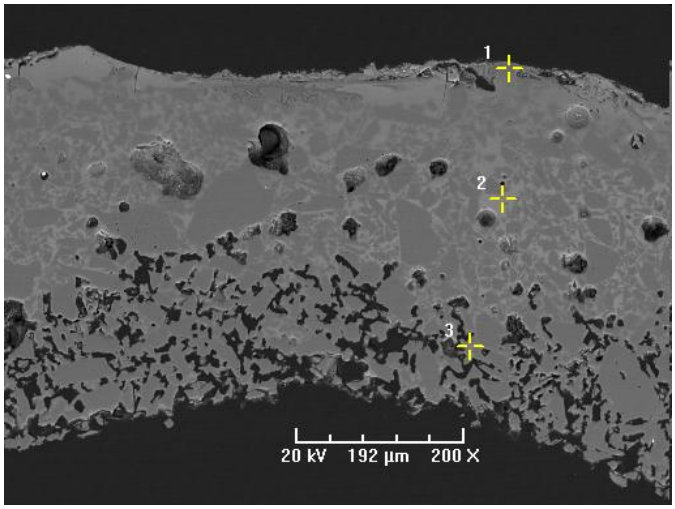


Figure F.67: Profile 1 of Middle Kingdom bead 2130-4, efflorescence.

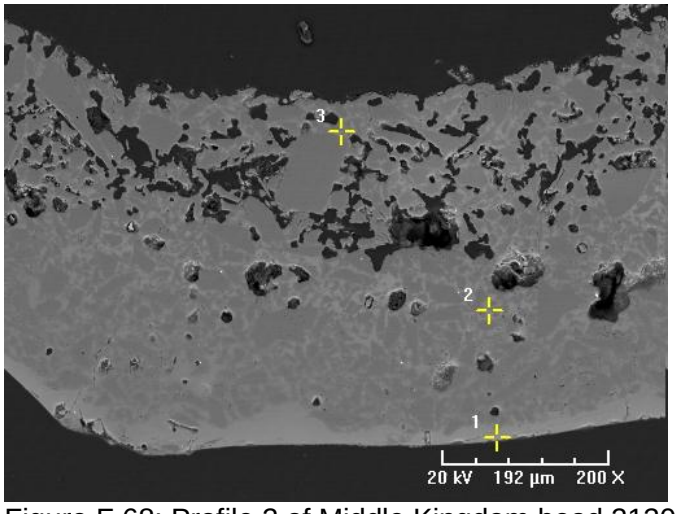


Figure F.68: Profile 2 of Middle Kingdom bead 2130-4, efflorescence.

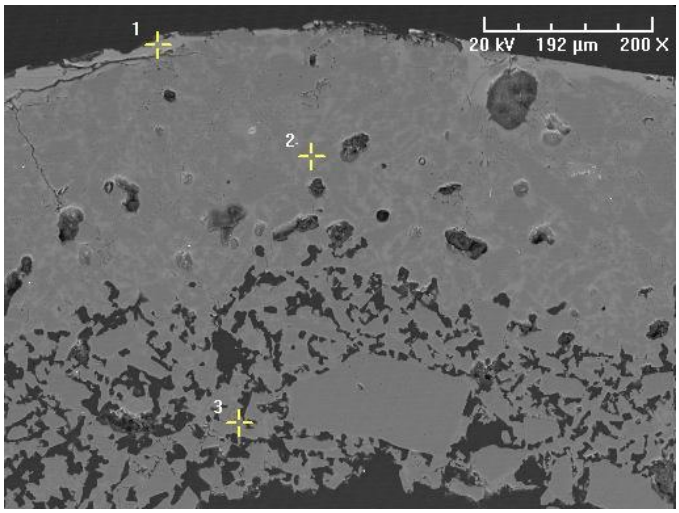


Figure F.69: Profile 1 of Middle Kingdom bead 2130-5, efflorescence.

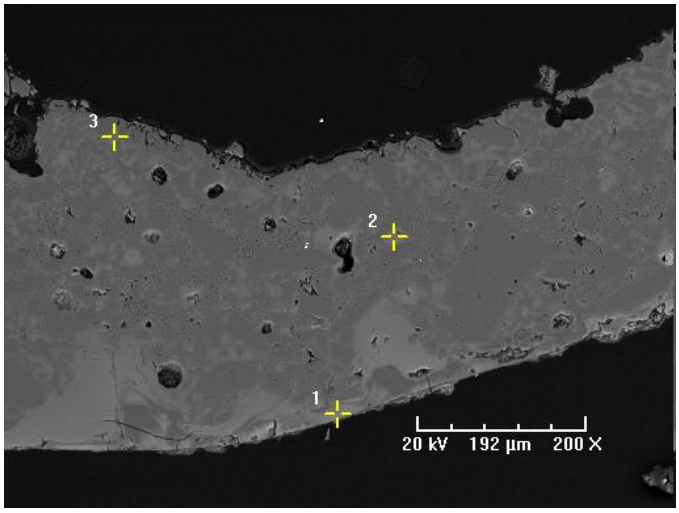


Figure F.70: Profile 2 of Middle Kingdom bead 2130-5, efflorescence.

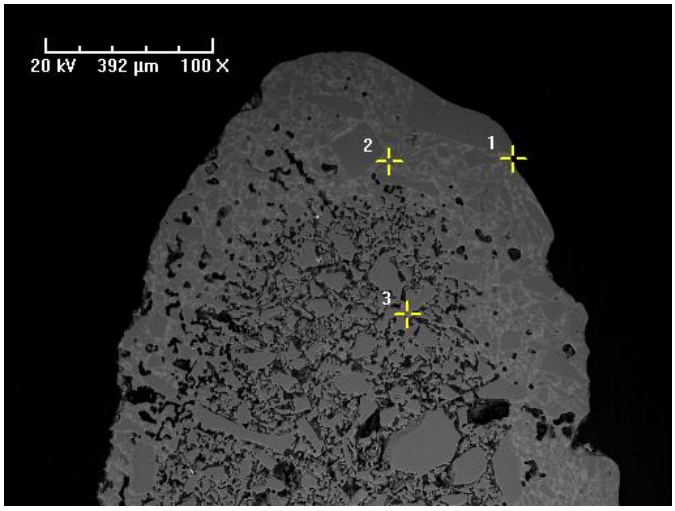


Figure F.71: Profile 1 of Middle Kingdom bead 2130-6, efflorescence.

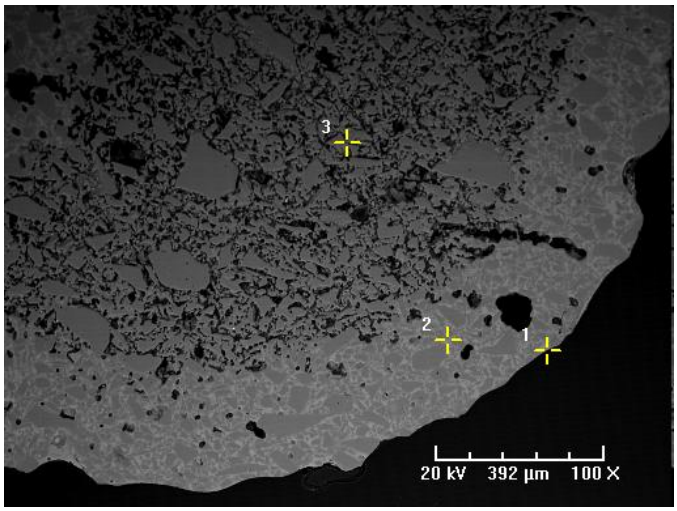


Figure F.72: Profile 2 of Middle Kingdom bead 2130-6, efflorescence.

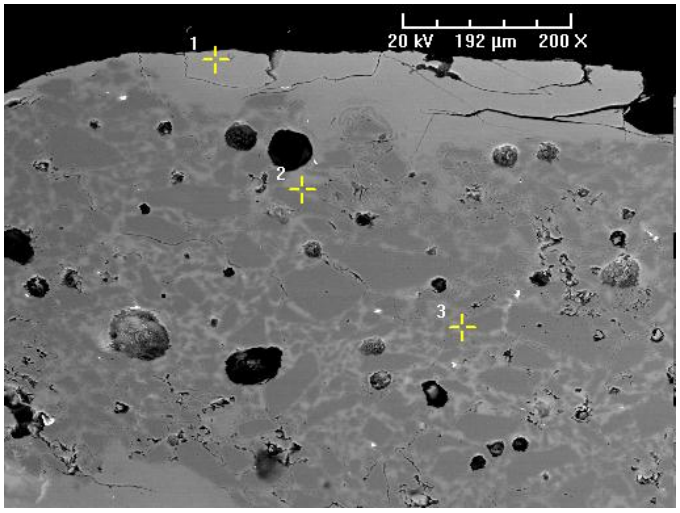


Figure F.73: Profile 1 of Middle Kingdom bead 2130-7, efflorescence.

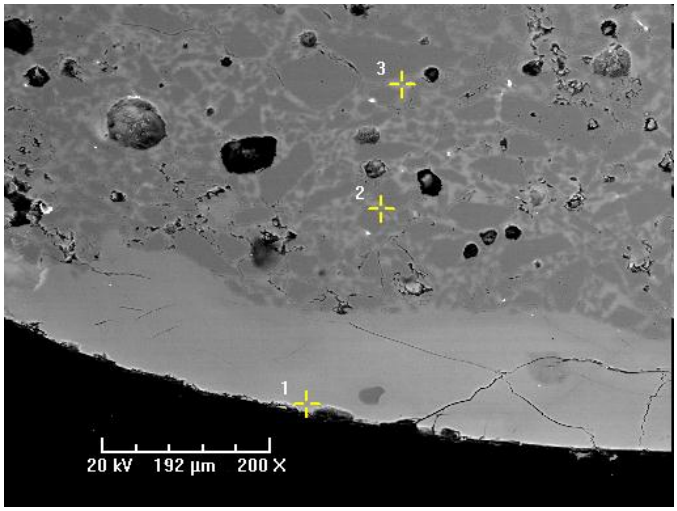


Figure F.74: Profile 2 of Middle Kingdom bead 2130-7, efflorescence.

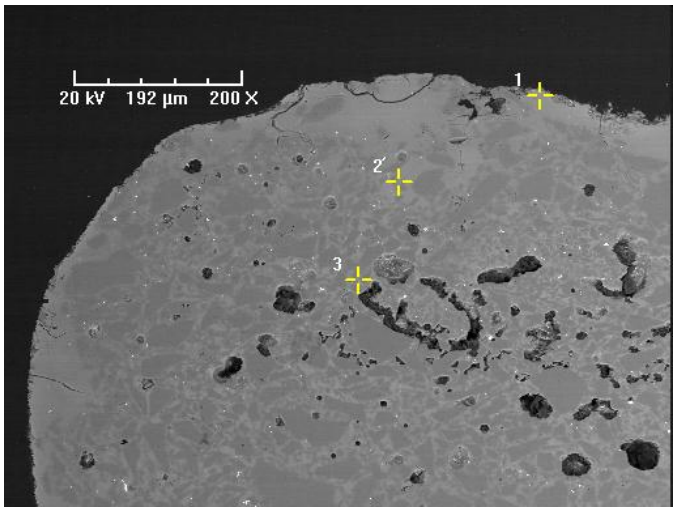


Figure F.75: Profile 1 of Middle Kingdom bead 2130-8, efflorescence.

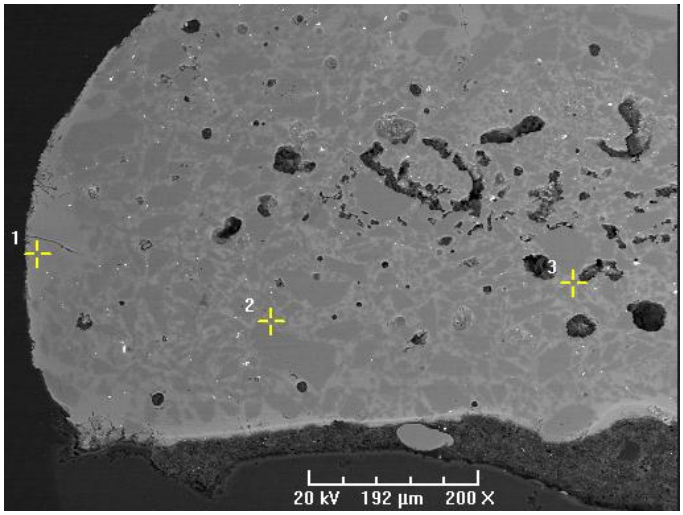


Figure F.76: Profile 2 of Middle Kingdom bead 2130-8, efflorescence.

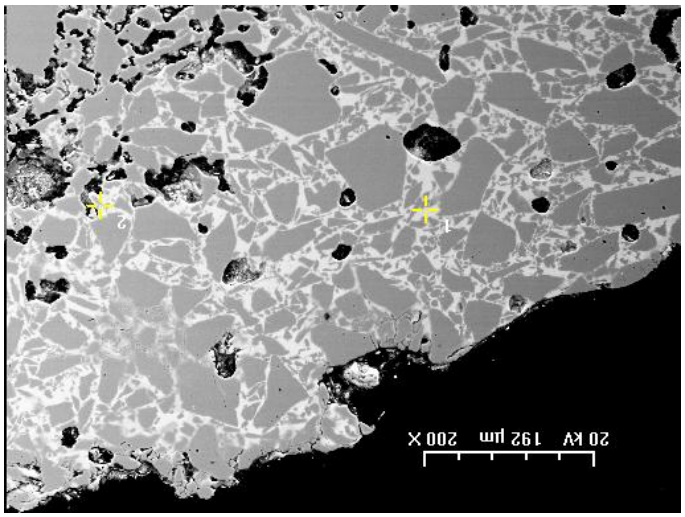


Figure F.77: Profile 1 of Middle Kingdom bead 2130-9, efflorescence.

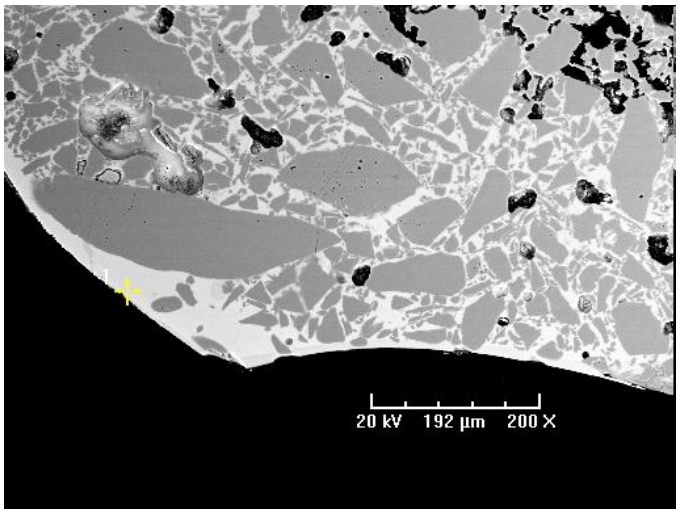


Figure F.78: Profile 2 of Middle Kingdom bead 2130-9, efflorescence.

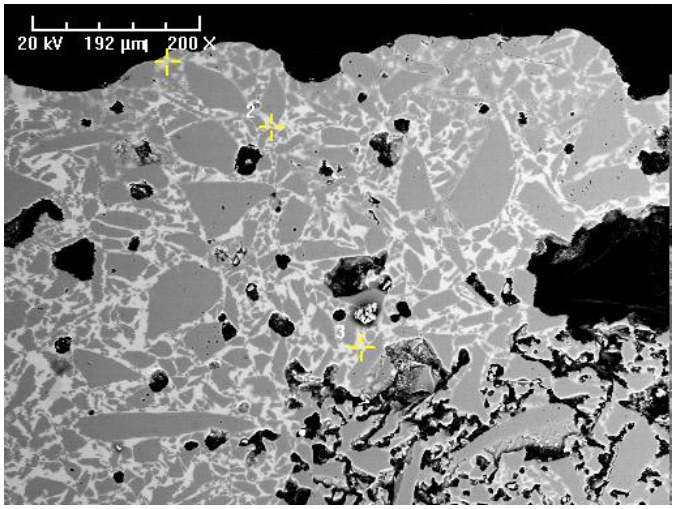


Figure F.79: Profile 1 of Middle Kingdom bead 2130-10, efflorescence.

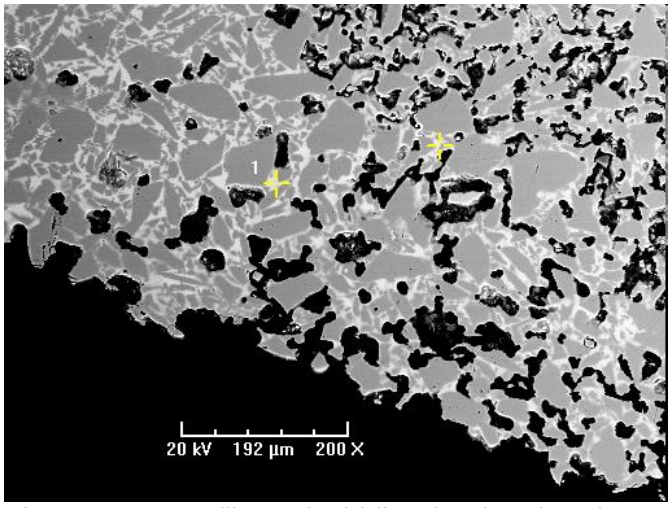


Figure F.80: Profile 2 of Middle Kingdom bead 2130-10, efflorescence.

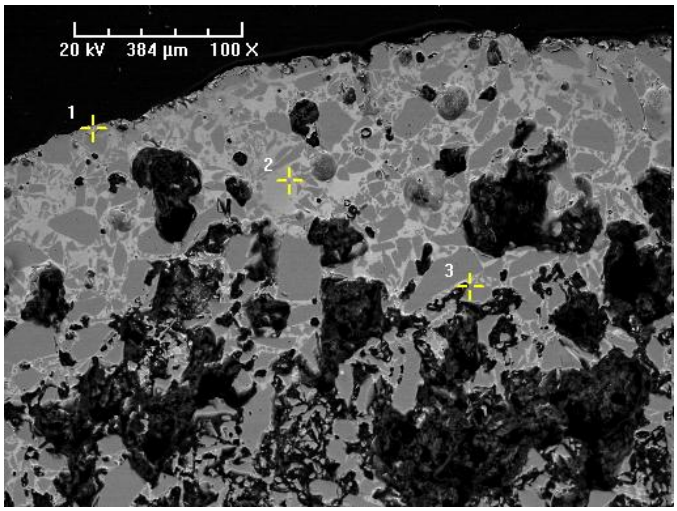


Figure F.81: Profile 1 of Middle Kingdom bead 2435-1, efflorescence.

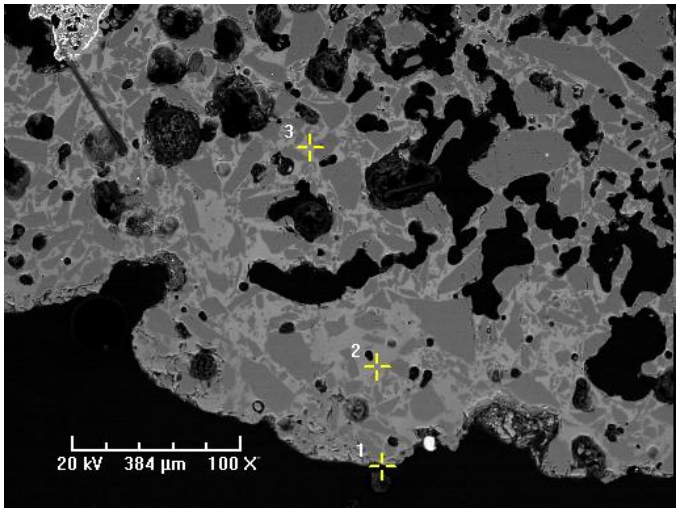


Figure F.82: Profile 2 of Middle Kingdom bead 2435-1, efflorescence.

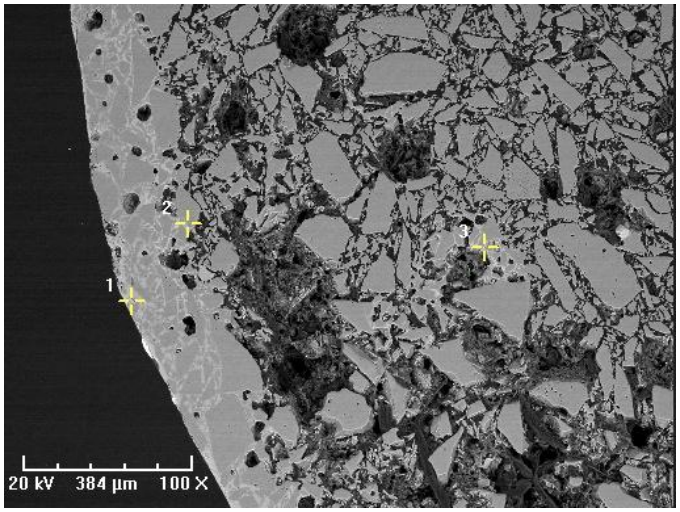


Figure F.83: Profile 1 of Middle Kingdom bead 2435-2, cementation.

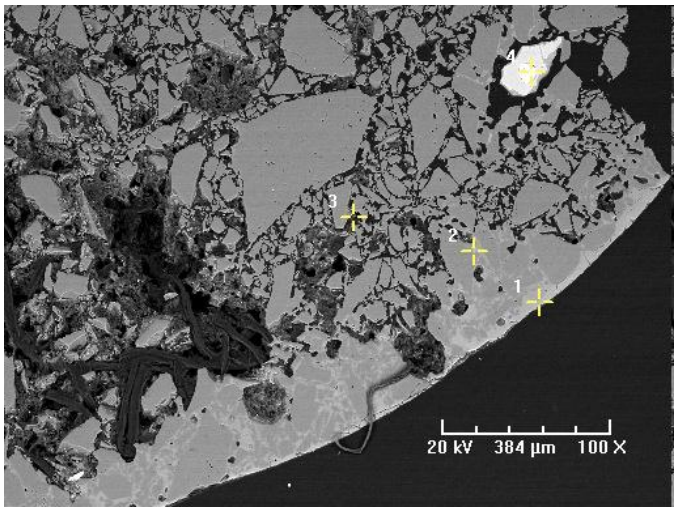


Figure F.84: Profile 2 of Middle Kingdom bead 2435-2, cementation.

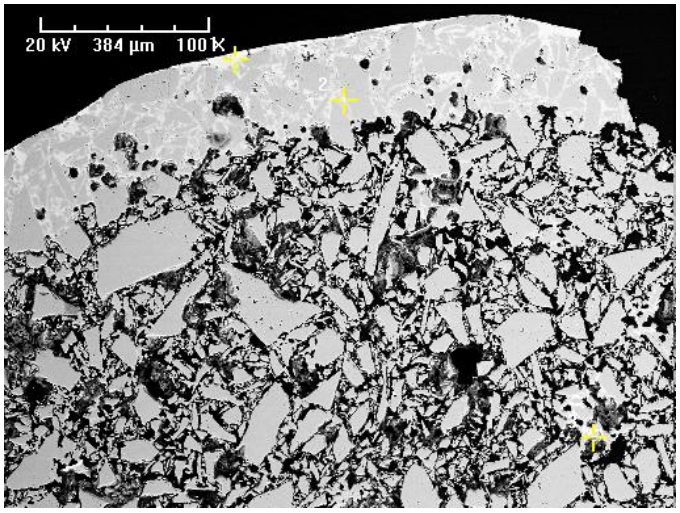


Figure F.85: Profile 1 of Middle Kingdom bead 2435-3, cementation.

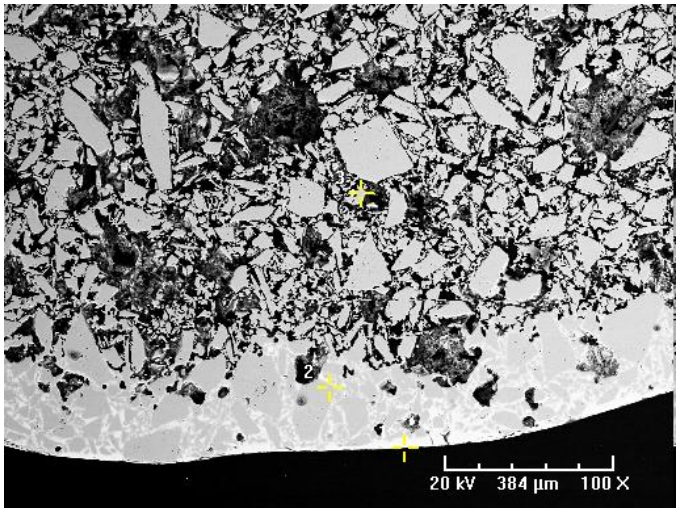


Figure F.86: Profile 2 of Middle Kingdom bead 2435-3, cementation.

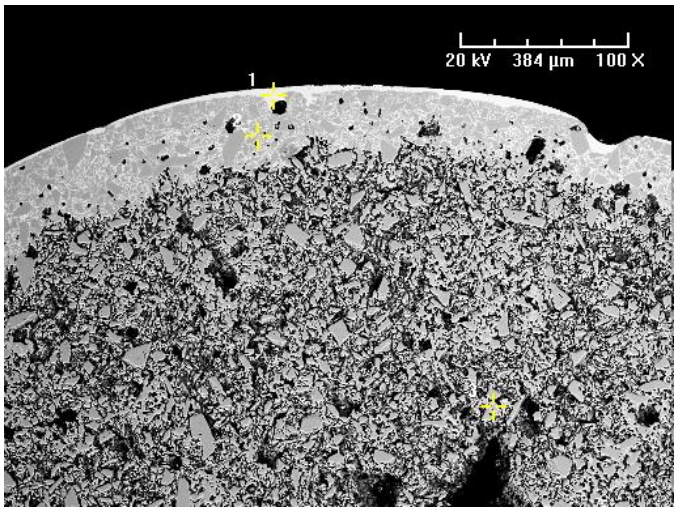


Figure F.87: Profile 1 of Middle Kingdom bead 2435-4, cementation.

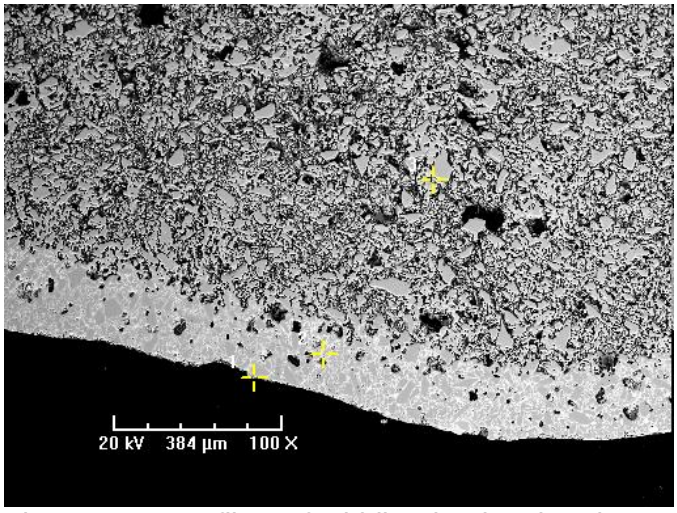


Figure F.88: Profile 2 of Middle Kingdom bead 2435-4, cementation.

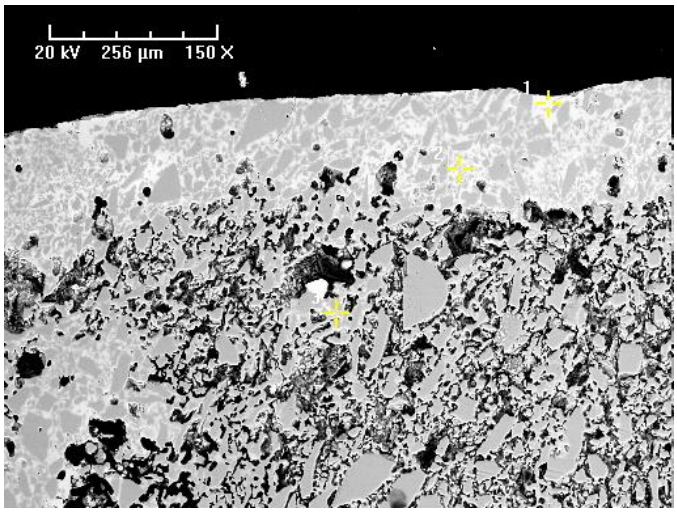


Figure F.89: Profile 1 of Middle Kingdom bead 2435-5, cementation.

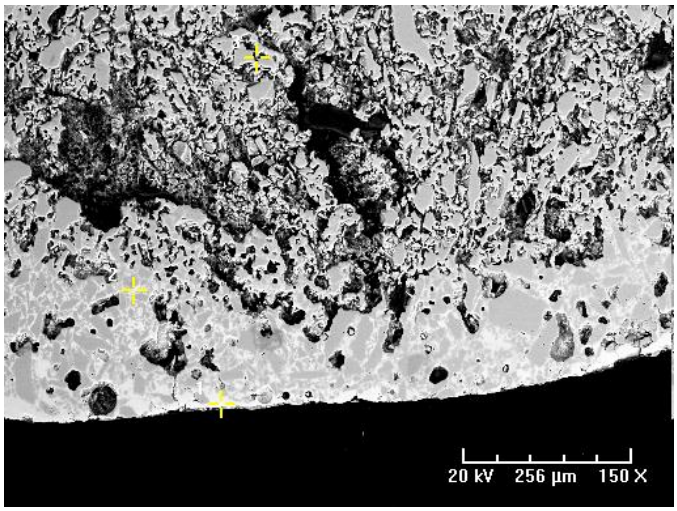


Figure F.90: Profile 2 of Middle Kingdom bead 2435-5, cementation.

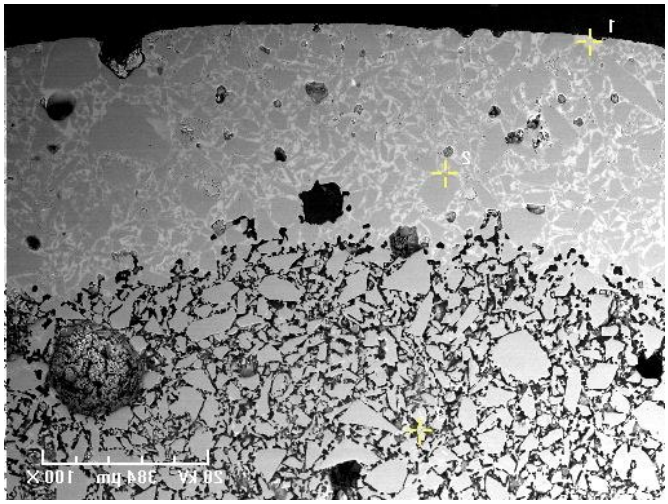


Figure F.91: Profile 1 of Middle Kingdom bead 2383-1, cementation.

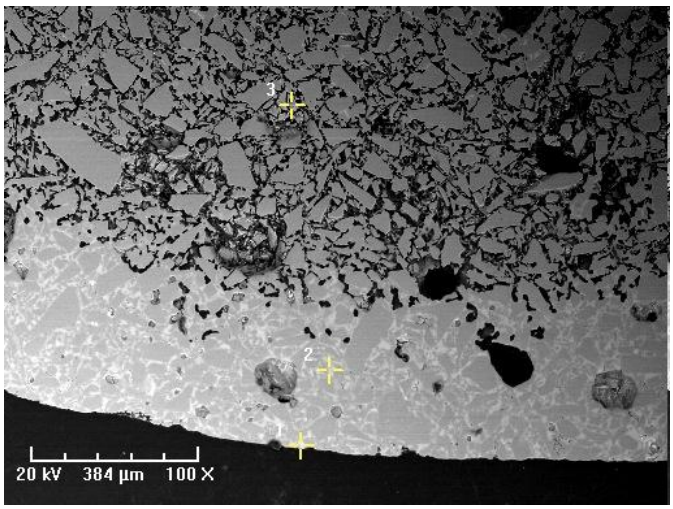


Figure F.92: Profile 2 of Middle Kingdom bead 2383-1, cementation.

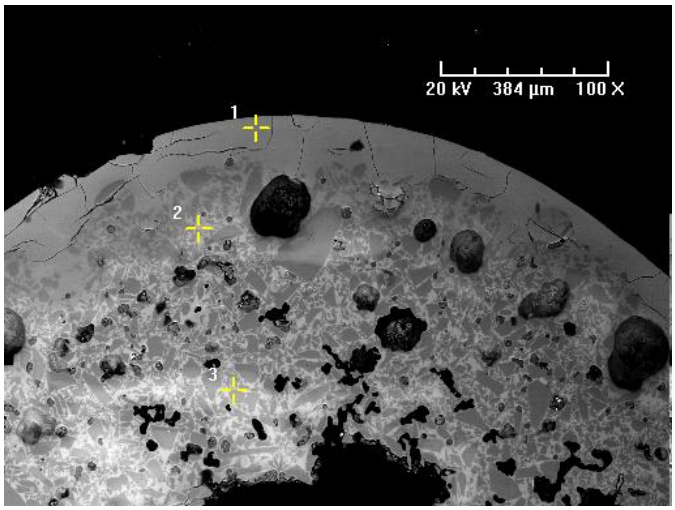


Figure F.93: Profile 1 of Middle Kingdom bead 2383-2, efflorescence.

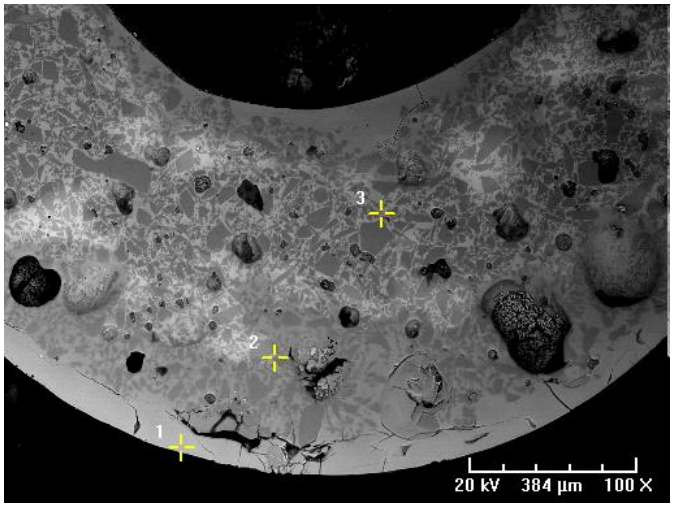


Figure F.94: Profile 2 of Middle Kingdom bead 2383-2, efflorescence.

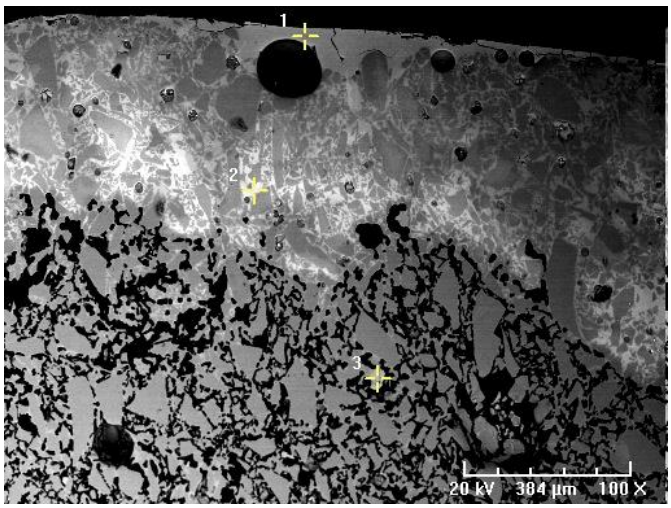


Figure F.95: Profile 1 of Middle Kingdom bead 2383-3, cementation.

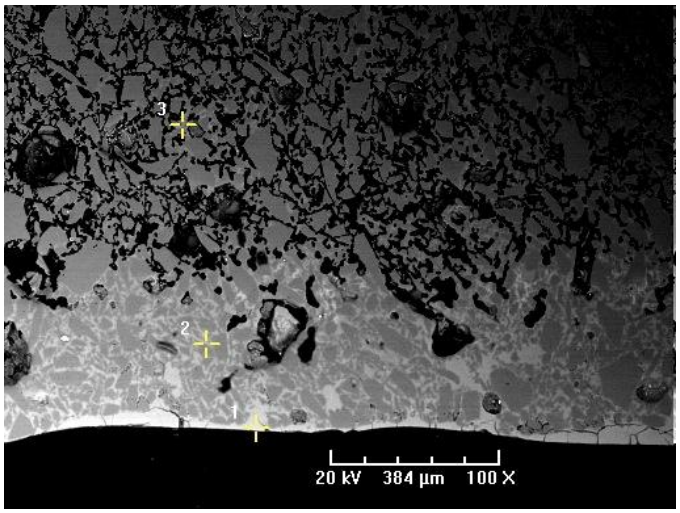


Figure F.96: Profile 2 of Middle Kindom bead 2383-3, cementation.

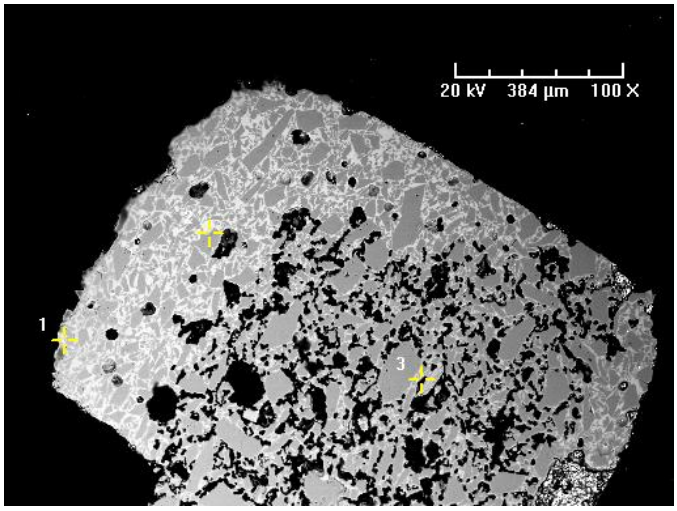


Figure F.97: Profile 1 of Middle Kingdom bead 2383-4, efflorescence.

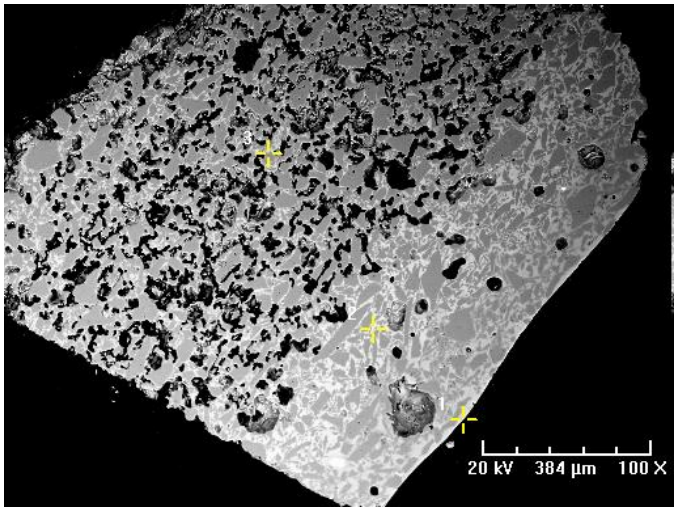


Figure F.98: Profile 2 of Middle Kingdombead 2383-4, efflorescence.

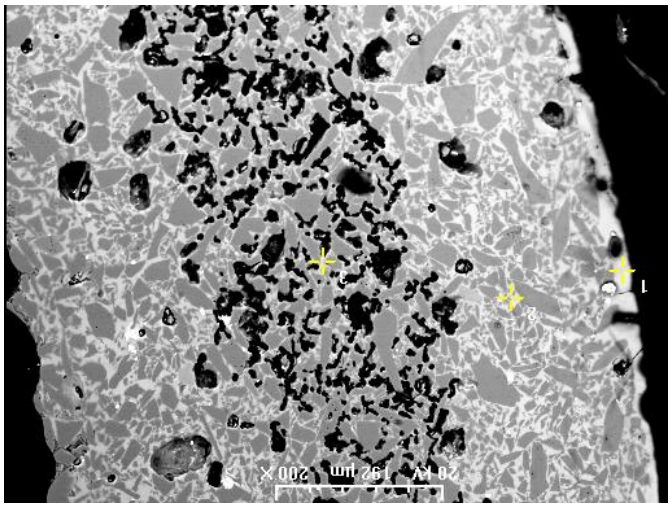


Figure F.99: Profile 1 of Middle Kingdom bead 2383-5, efflorescence.

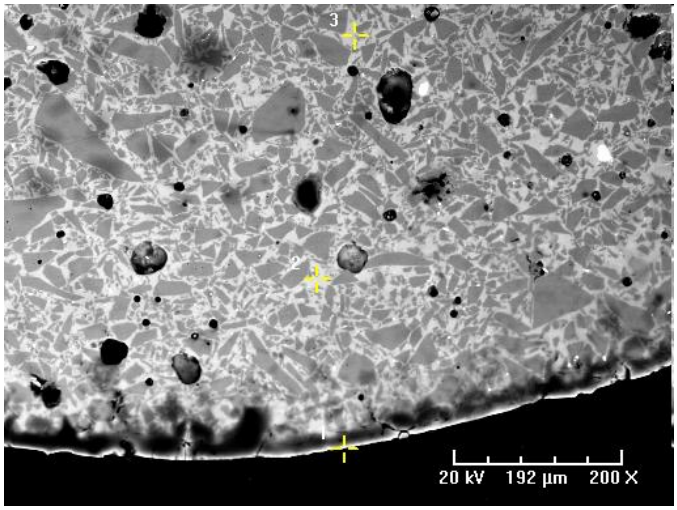


Figure F.100: Profile 2 of Middle Kingdom bead 2383-5, efflorescence.

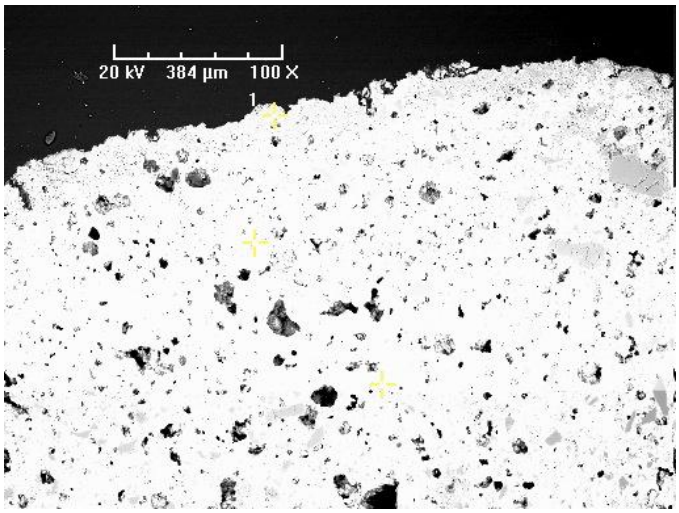


Figure F.101: Profile 1 of Middle Kingdom bead 2383-6, cementation.

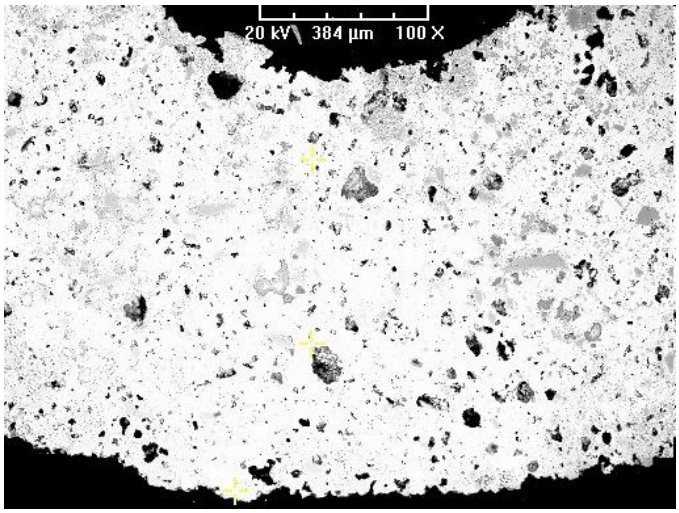


Figure F.102: Profile 2 of Middle Kingdom bead 2383-6, cementation.

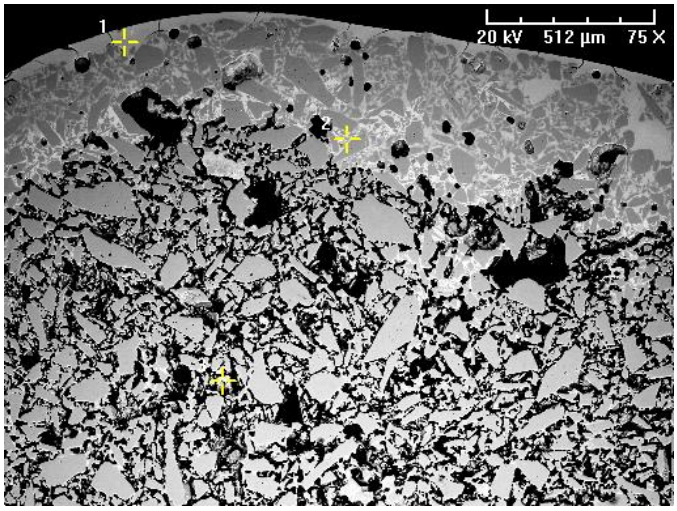


Figure F.103: Profile 1 of Second Intermediate Period bead 2385-1, cementation.

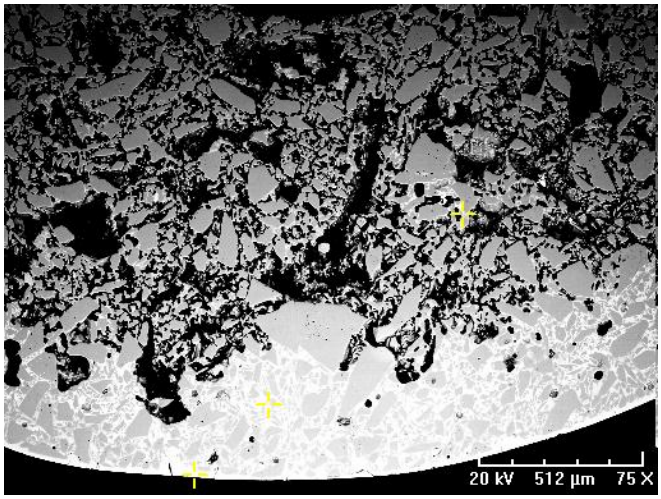


Figure F.104: Profile 2 of Second Intermediate Period bead 2385-1, cementation.

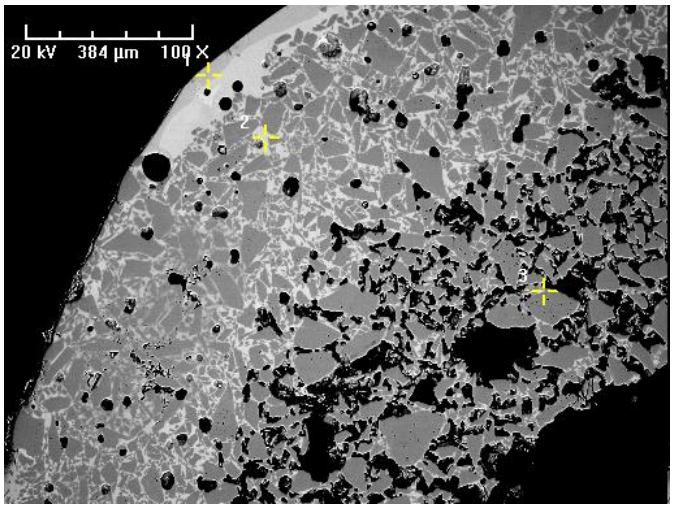


Figure F.105: Profile 1 of Second Intermediate Period bead 2385-2, efflorescence.

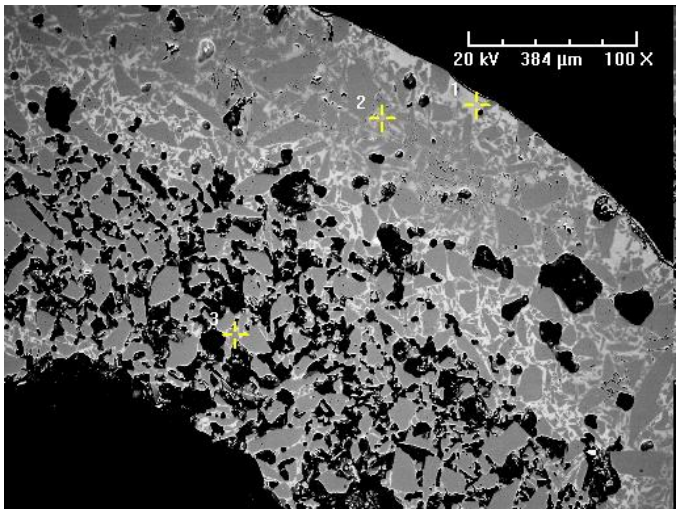


Figure F.106: Profile 2 of Second Intermediate Period bead 2385-2, efflorescence.

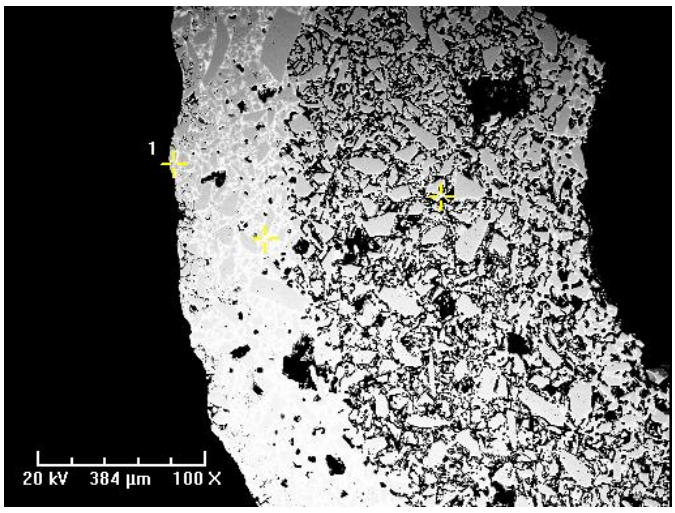


Figure F.107: Profile 1 of Second Intermediate Period bead 2385-3, efflorescence.

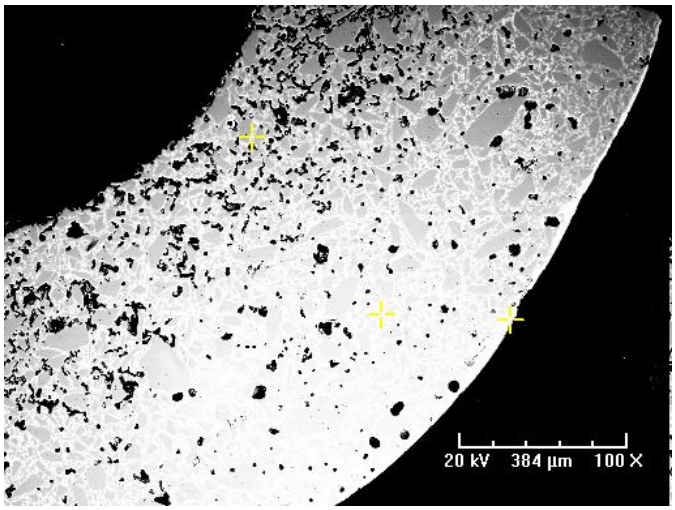


Figure F.108: Profile 2 of Second Intermediate Period bead 2385-3, efflorescence.

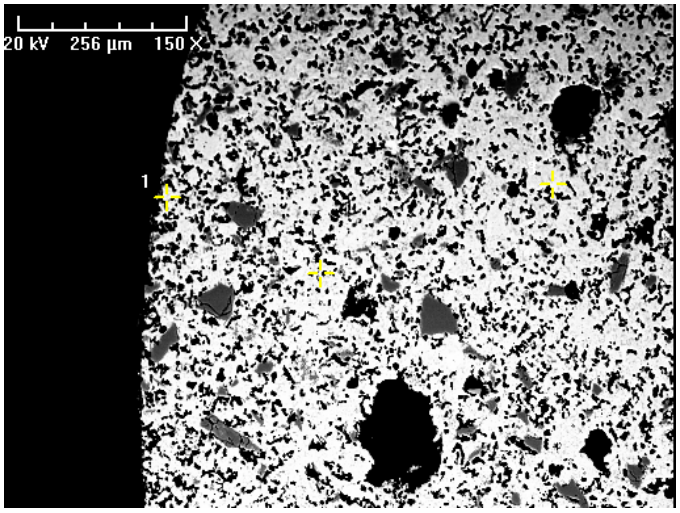


Figure F.109: Profile 1 of Second Intermediate Period bead 2385-4, unknown.

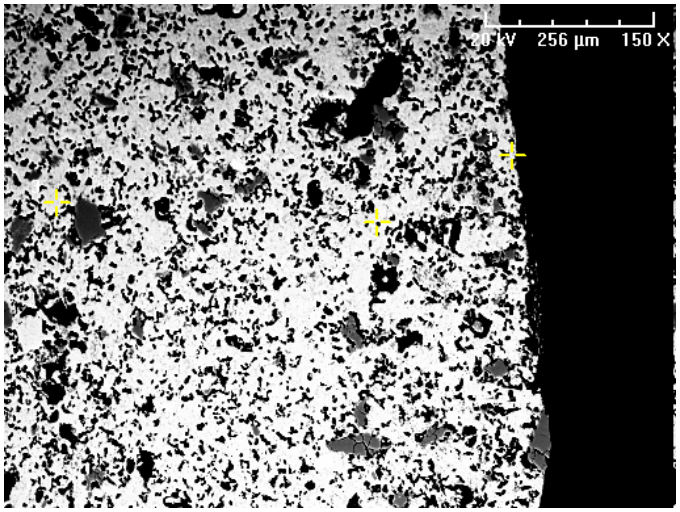


Figure F.110: Profile 2 of Second Intermediate Period bead 2385-4, unknown.

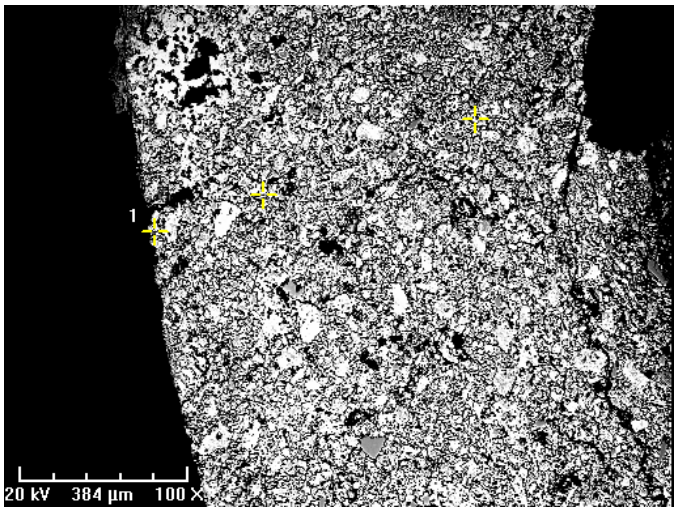


Figure F.111: Profile 1 of Second Intermediate Period bead 2385-5, unknown.

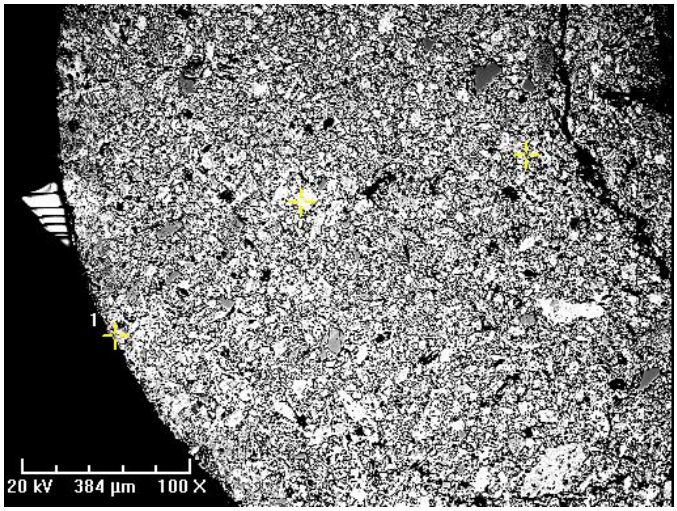


Figure F.112: Profile 2 of Second Intermediate Period bead 2385-5, unknown.

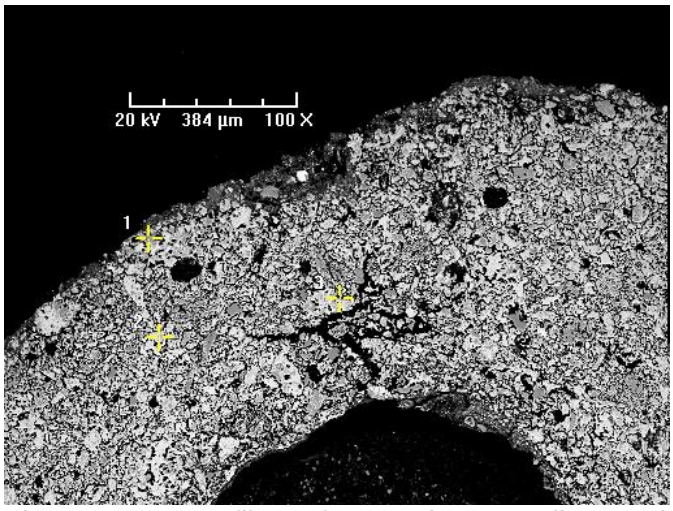


Figure F.113: Profile 1 of Second Intermediate Period bead 2385-6, unknown.

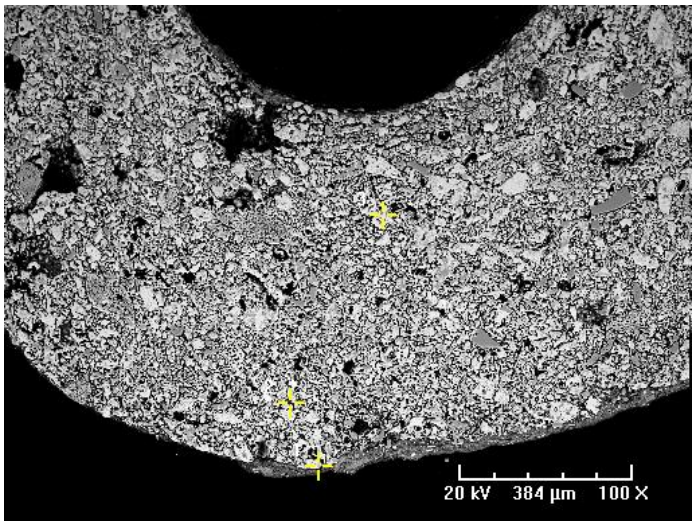


Figure F.114: Profile 2 of Second Intermediate Period bead 2385-6, unknown.

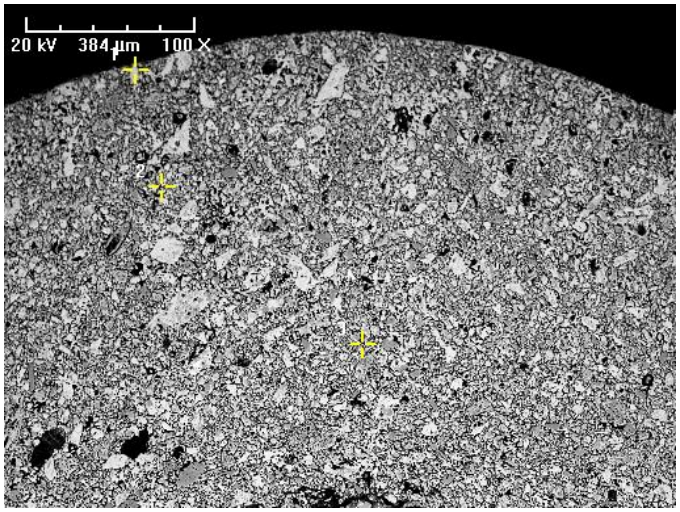


Figure F.115: Profile 1 of Second Intermediate Period bead 2385-7, unknown.

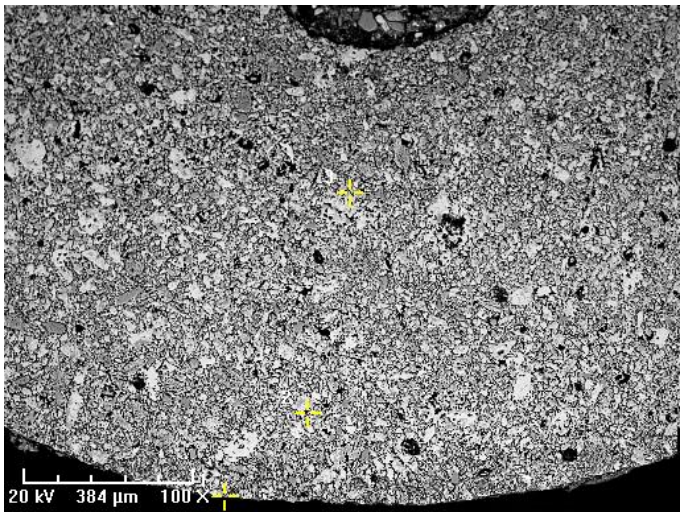


Figure F.116: Profile 2 of Second Intermediate Period bead 2385-7, unknown.

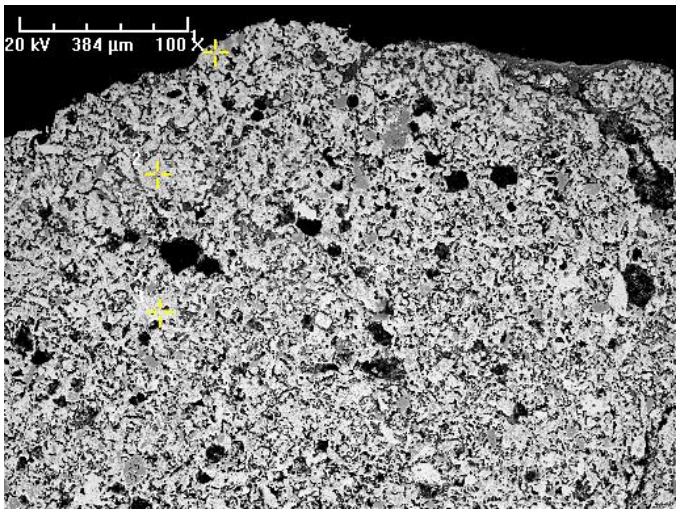


Figure F.117: Profile 1 of Second Intermediate Period bead 2385-8, unknown.

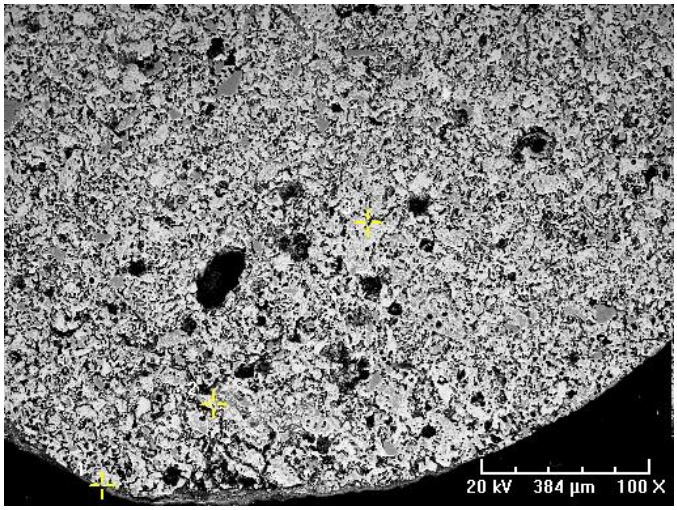


Figure F.118: Profile 2 of Second Intermediate Period bead 2385-8, unknown.

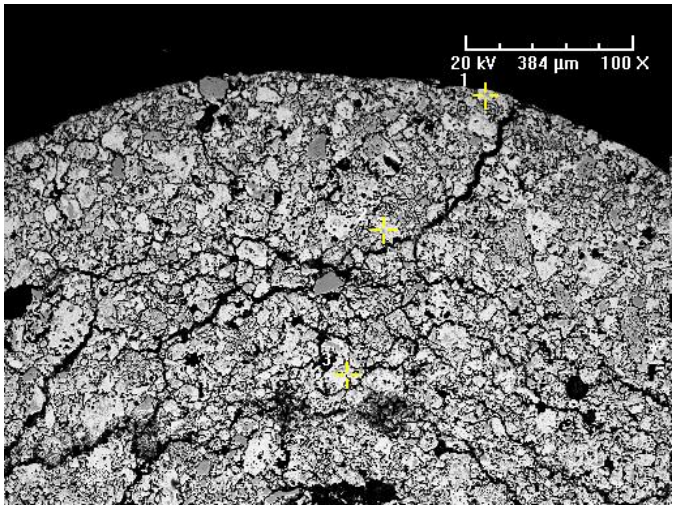


Figure F.119: Profile 1 of Second Intermediate Period bead 2385-9, unknown.

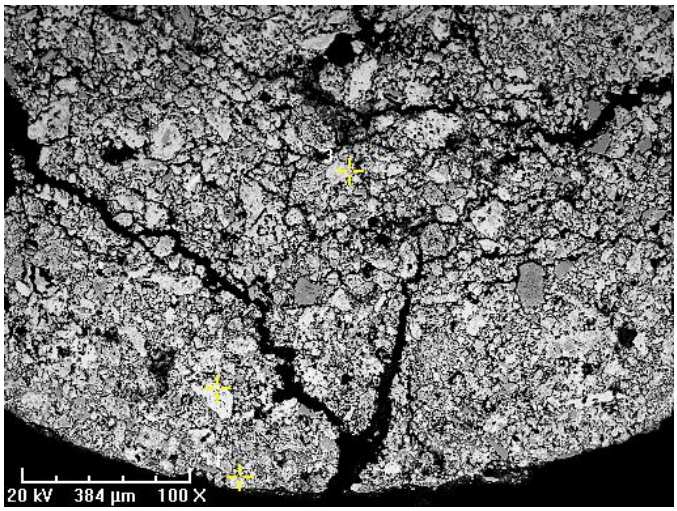


Figure F.120: Profile 2 of Second Intermediate Period bead 2385-9, unknown.

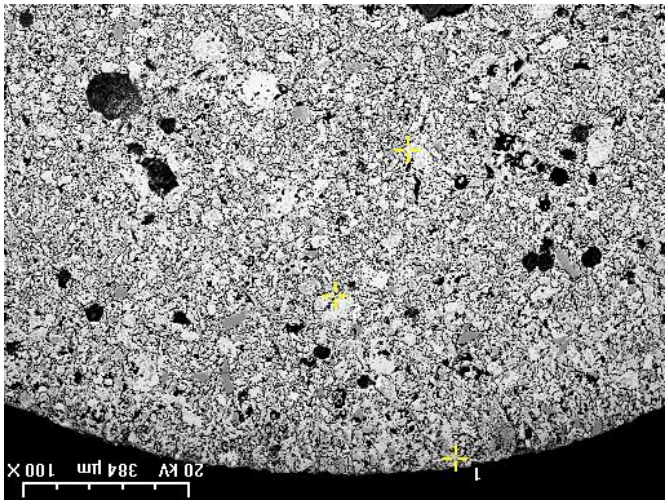


Figure F.121: Profile 1 of Second Intermediate Period bead 2385-10, unknown.

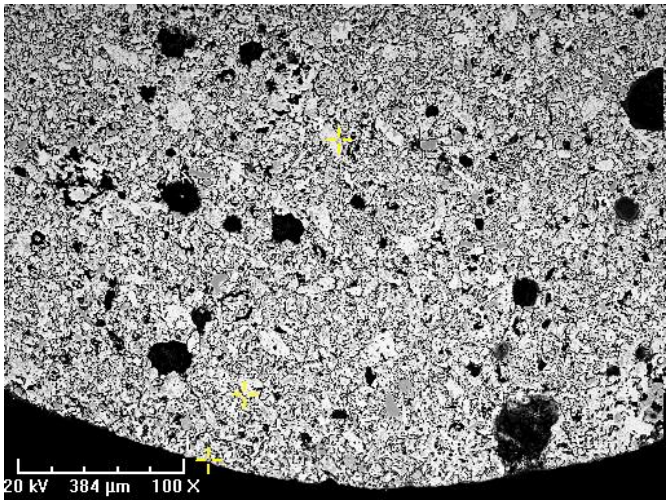


Figure F.122: Profile 2 of Second Intermediate Period bead 2385-10, unknown.

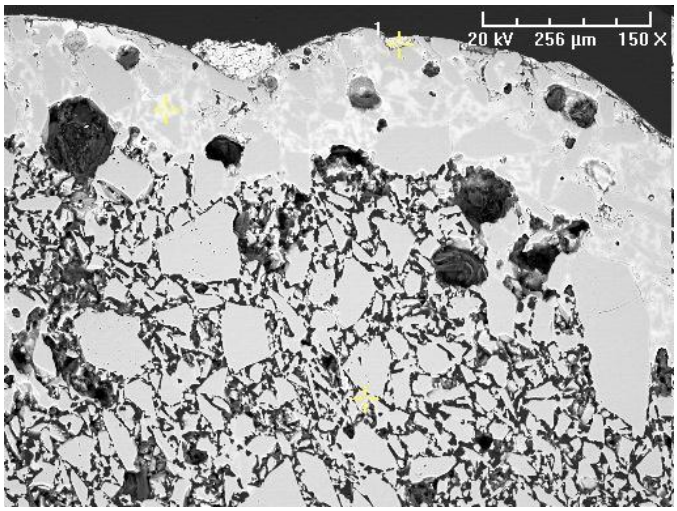


Figure F.123: Profile 1 of New Kingdom bead 2380-1, cementation.

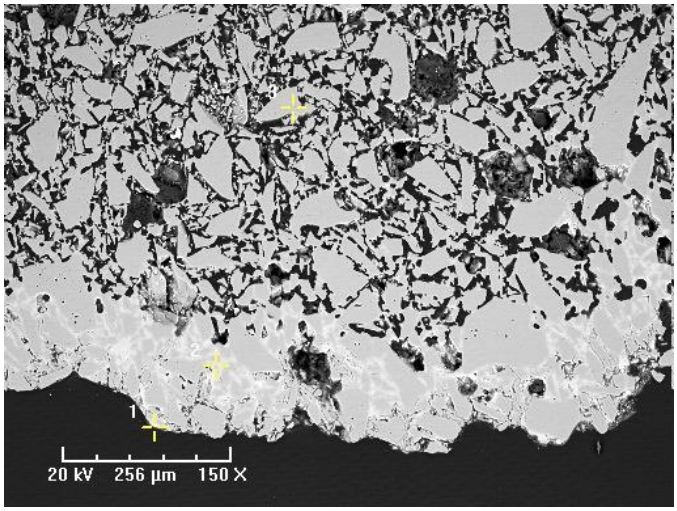


Figure F.124: Profile 2 of New Kingdom bead 2380-1, cementation.

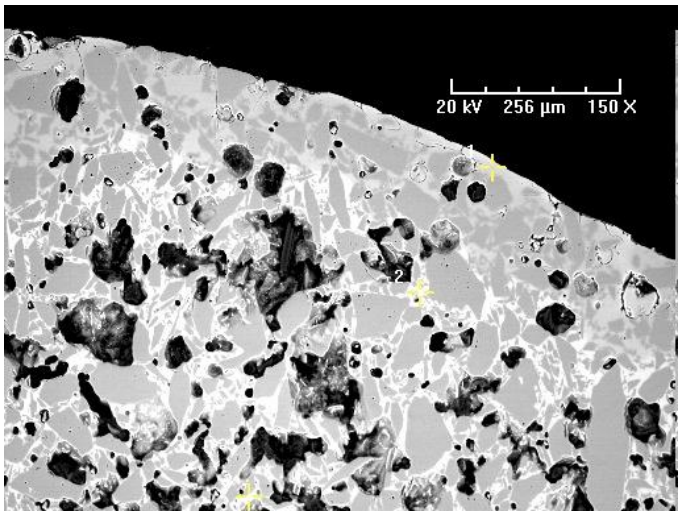


Figure F.125: Profile 1 of New Kingdom bead 2380-2, efflorescence.

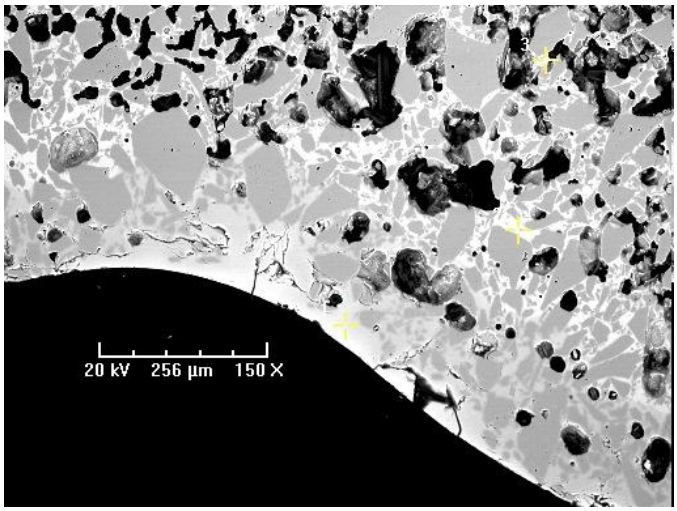


Figure F.126: Profile 2 of New Kingdom bead 2380-2, efflorescence.

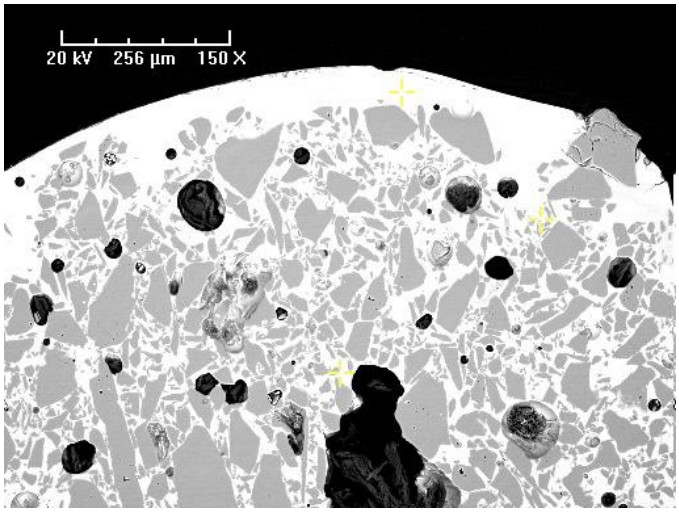


Figure F.127: Profile 1 of New Kingdom bead 2380-3, efflorescence.

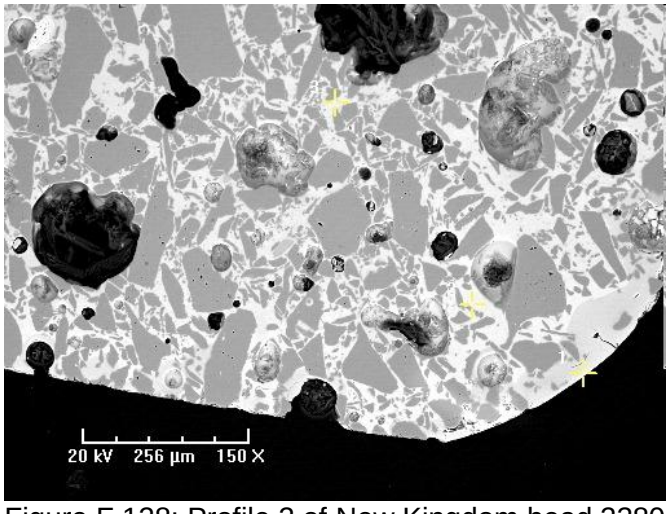


Figure F.128: Profile 2 of New Kingdom bead 2380-3, efflorescence.

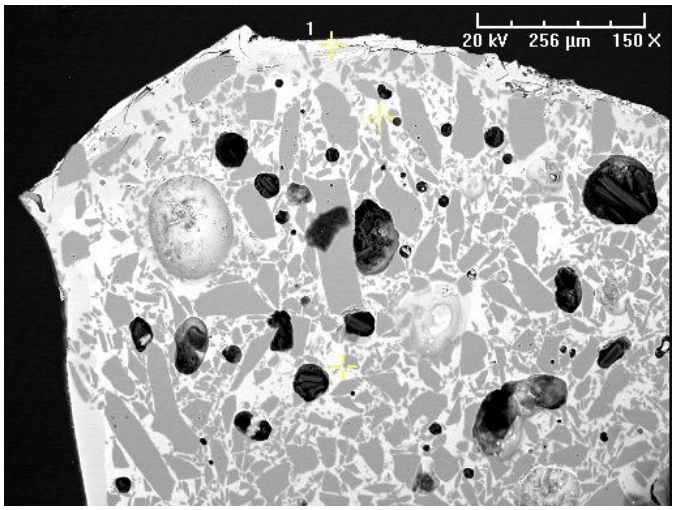


Figure F.129: Profile 1 of New Kingdom bead 2380-4, efflorescence.

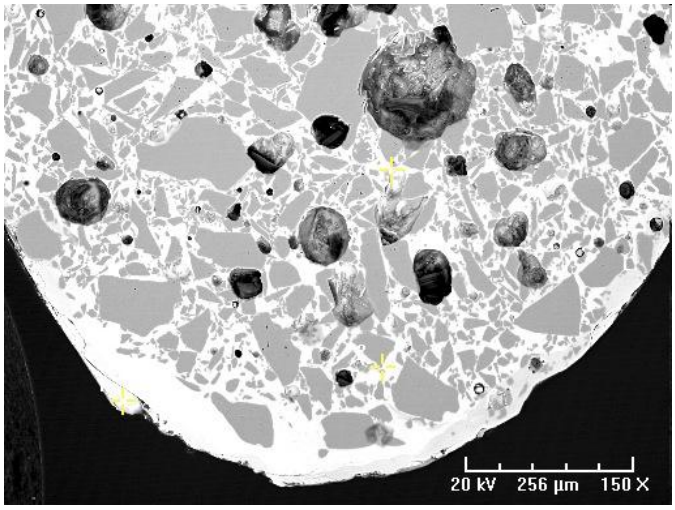


Figure F.130: Profile 2 of New Kingdom bead 2380-4, efflorescence.

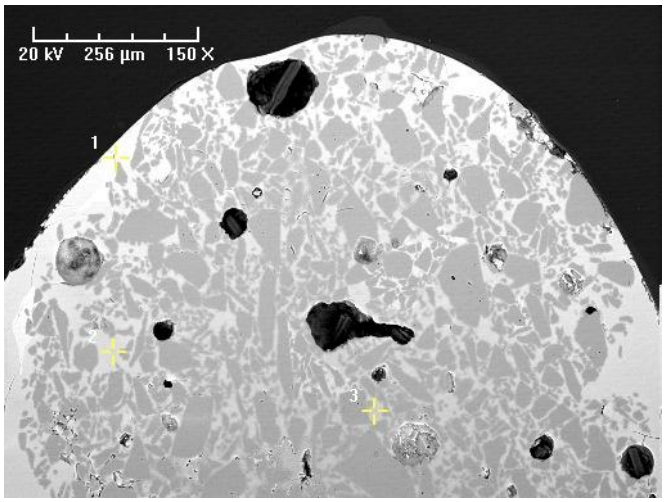


Figure F.131: Profile 1 of New Kingdom bead 2380-5, efflorescence.

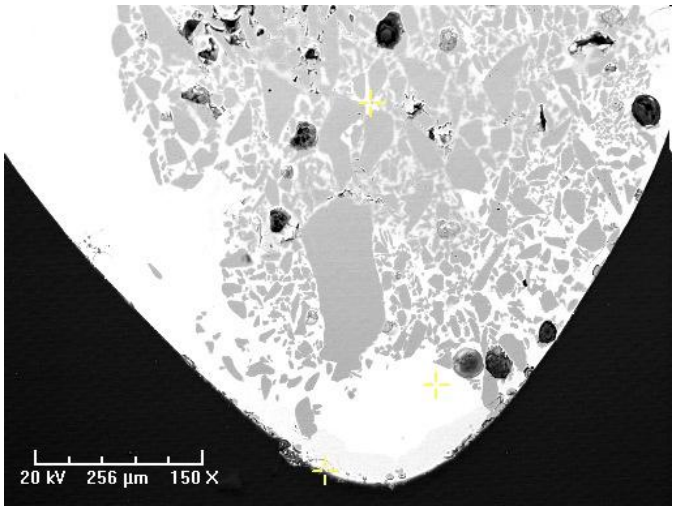


Figure F.132: Profile 2 of New Kingdom bead 2380-5, efflorescence.

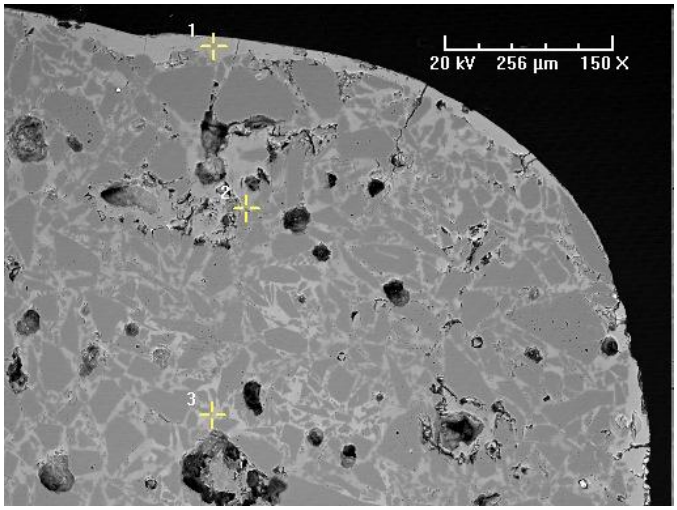


Figure F.133: Profile 1 of New Kingdom bead 2380-6, efflorescence.

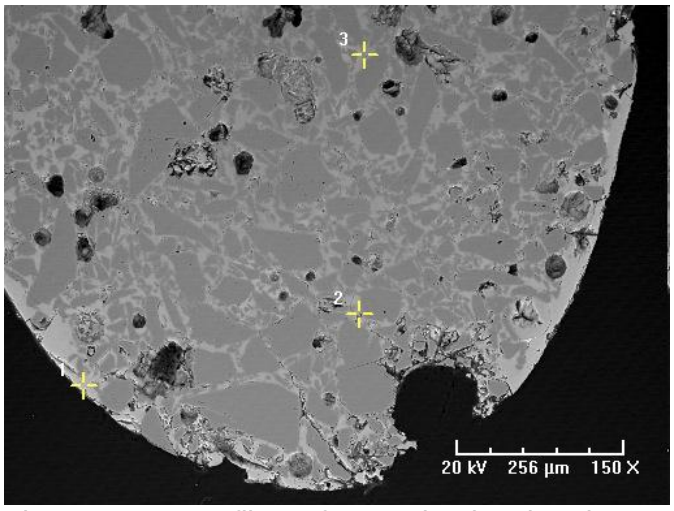


Figure F.134: Profile 2 of New Kingdom bead 2380-6, efflorescence.

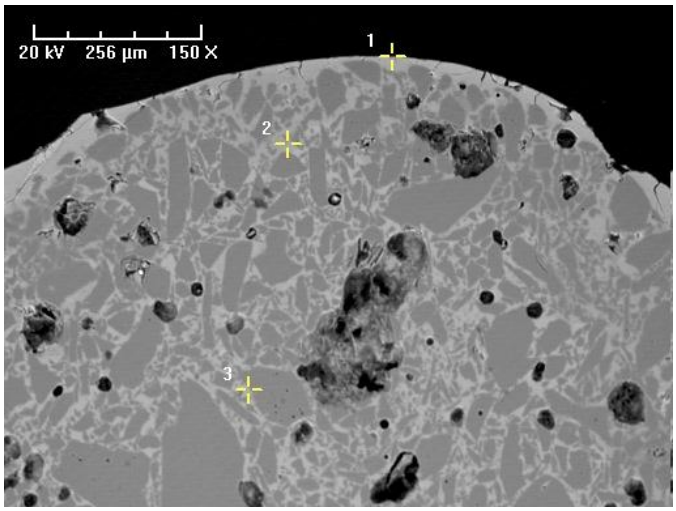


Figure F.135: Profile 1 of New Kingdom bead 2380-7, efflorescence.

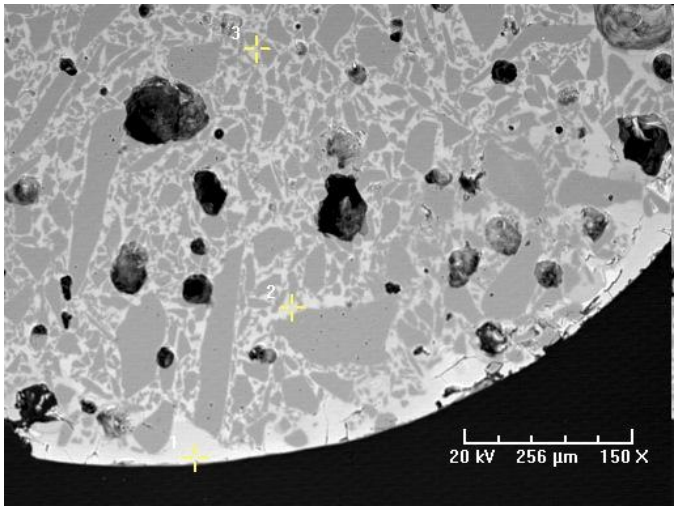


Figure F.136: Profile 2 of New Kingdom bead 2380-7, efflorescence.

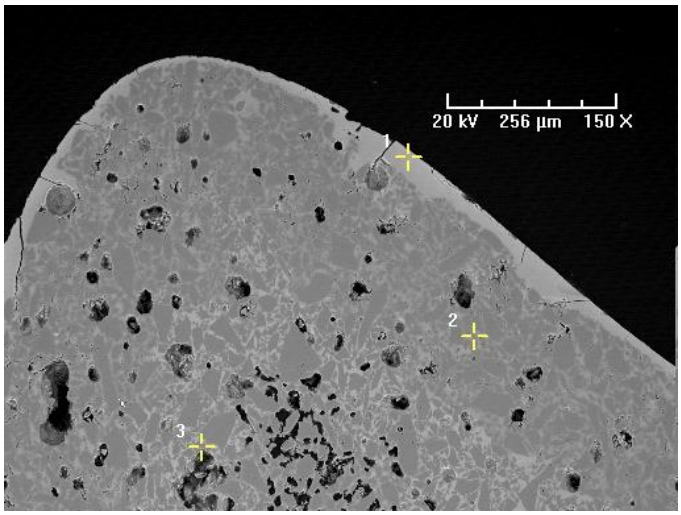


Figure F.137: Profile 1 of New Kingdom bead 2380-8, efflorescence.

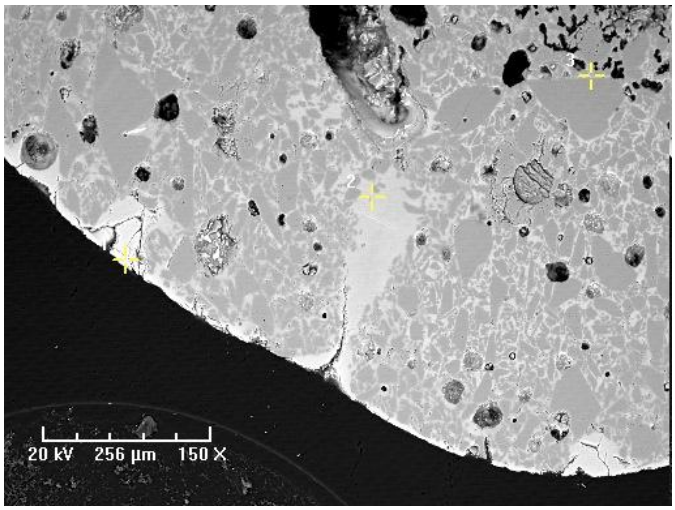


Figure F.138: Profile 2 of New Kingdom bead 2380-8, efflorescence.

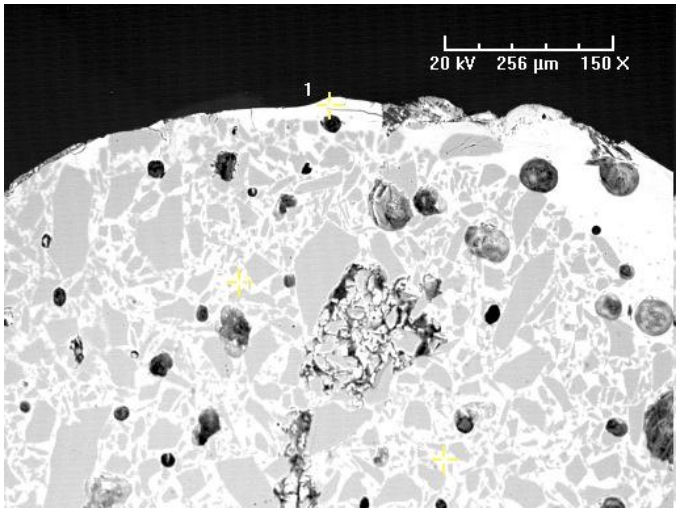


Figure F.139: Profile 1 of New Kingdom bead 2380-9, efflorescence.

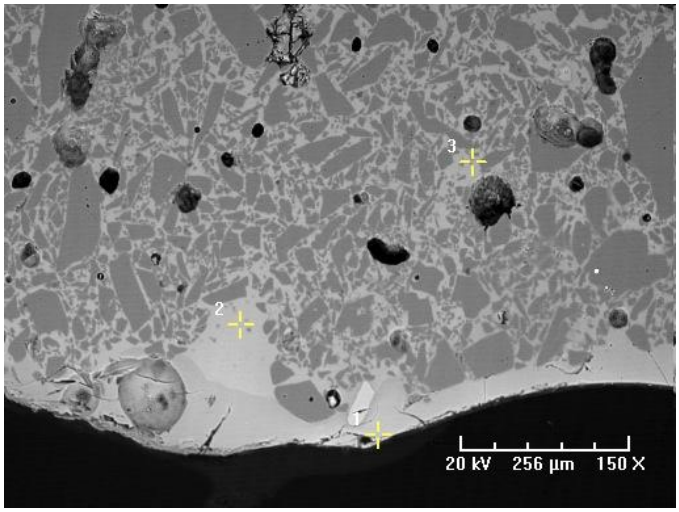


Figure F.140: Profile 2 of New Kingdom bead 2380-9, efflorescence.

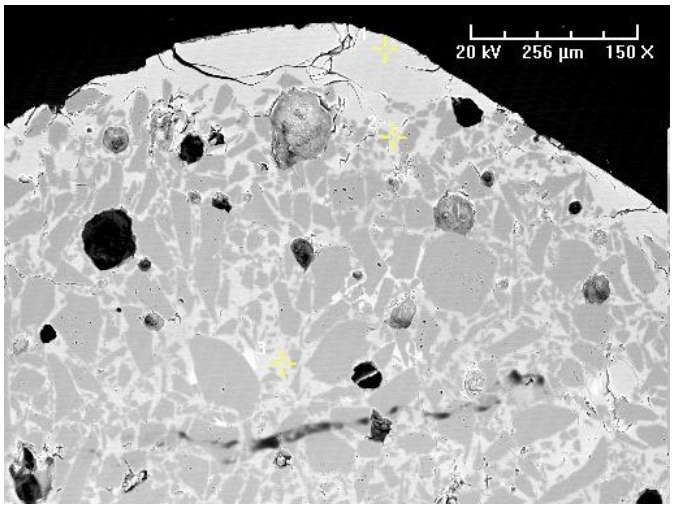


Figure F.141: Profile 1 of New Kingdom bead 2380-10, efflorescence.

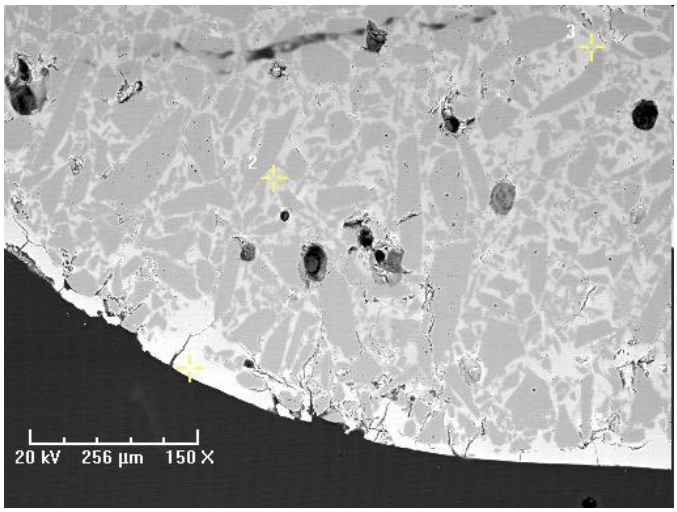


Figure F.142: Profile 2 of New Kingdom bead 2380-10, efflorescence.

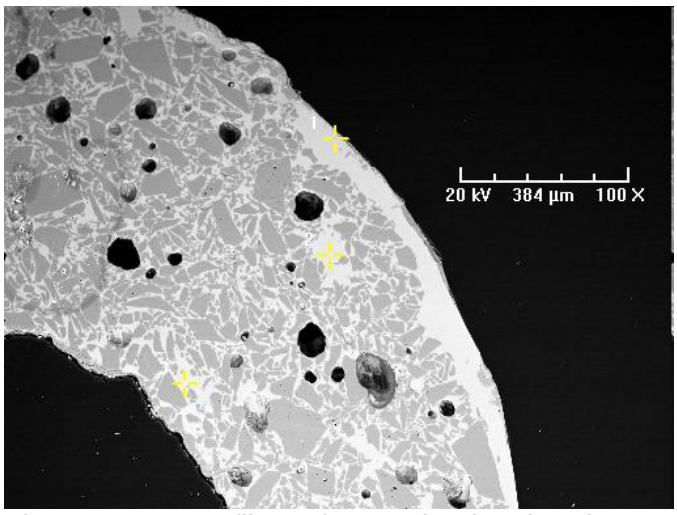


Figure F.143: Profile 1 of New Kingdom bead 2384-1, efflorescence.

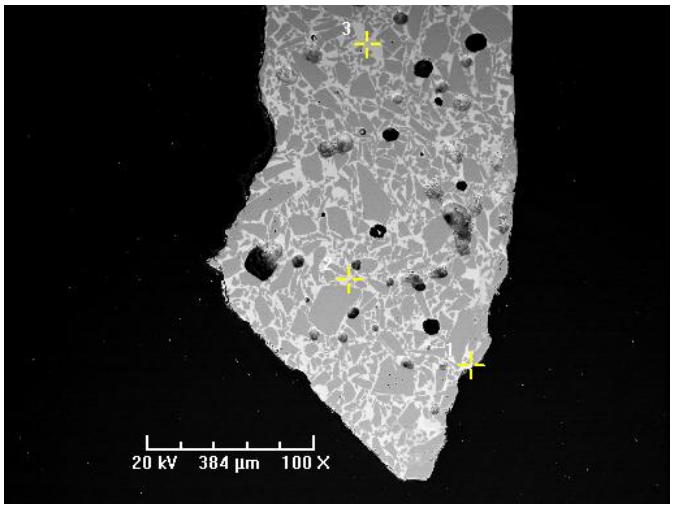


Figure F.144: Profile 2 of New Kingdom bead 2384-1, efflorescence.

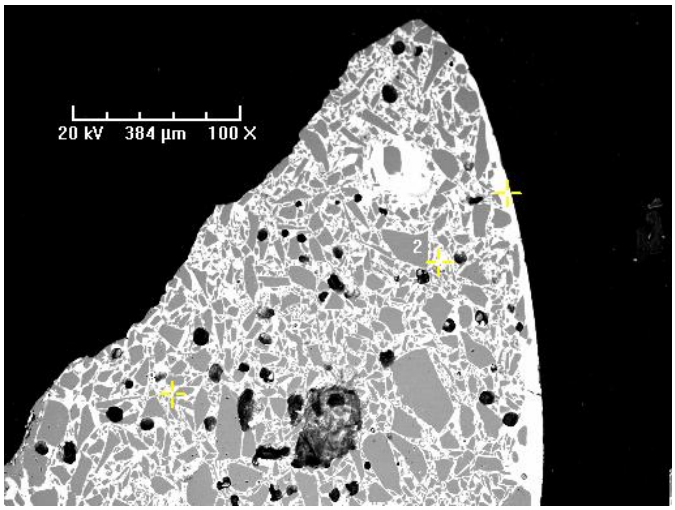


Figure F.145: Profile 1 of New Kingdom bead 2384-2, efflorescence.

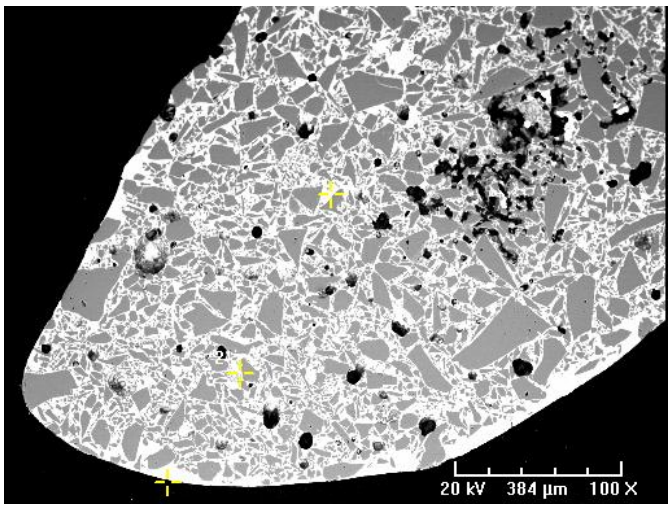


Figure F.146: Profile 2 of New Kingdom bead 2384-2, efflorescence.

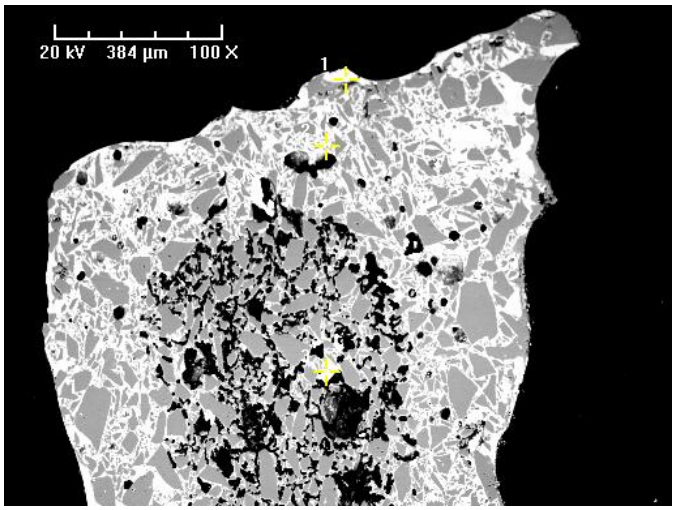


Figure F.147: Profile 1 of New Kingdom bead 2384-3, efflorescence.

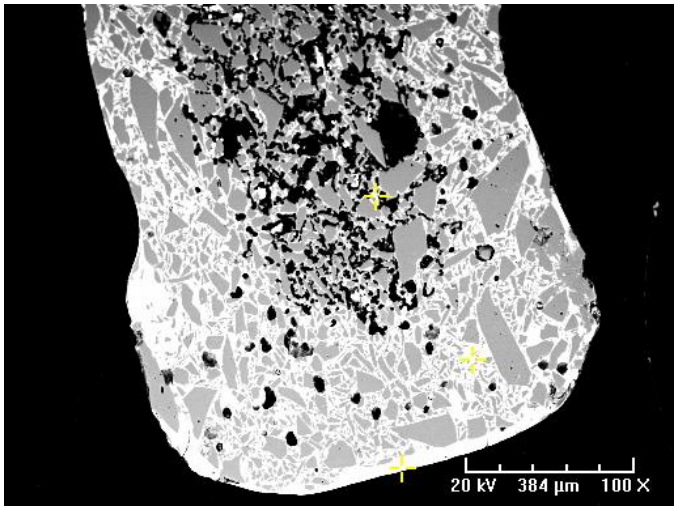


Figure F.148: Profile 2 of New Kingdom bead 2384-3, efflorescence.

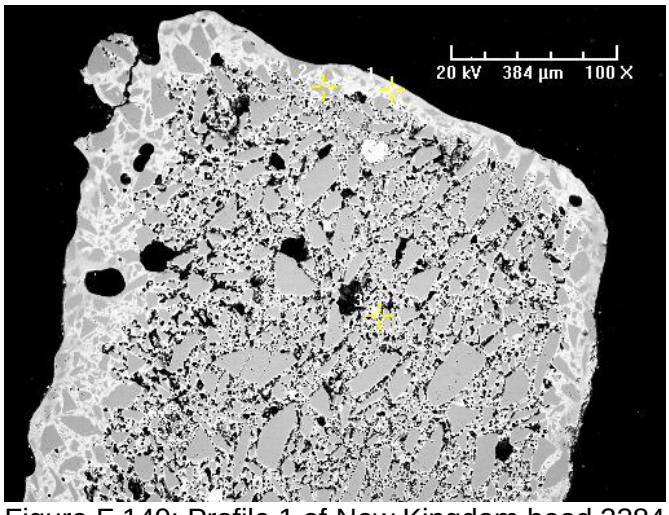


Figure F.149: Profile 1 of New Kingdom bead 2384-4, cementation.

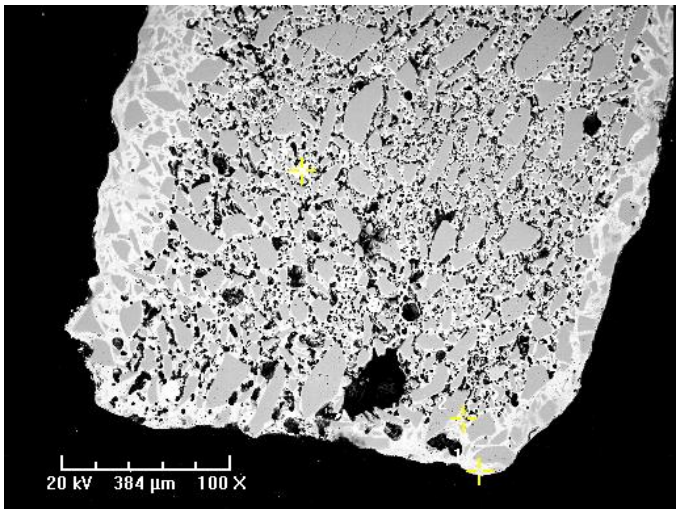


Figure F.150: Profile 2 of New Kingdom bead 2384-4, cementation.

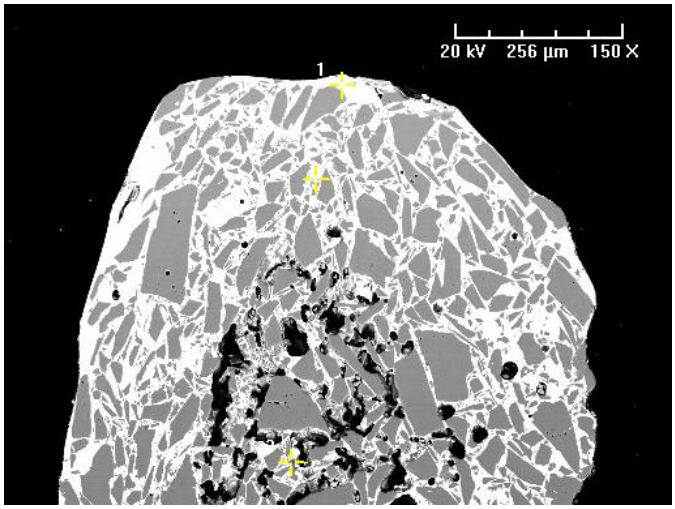


Figure F.151: Profile 1 of New Kingdom bead 2384-5, efflorescence.

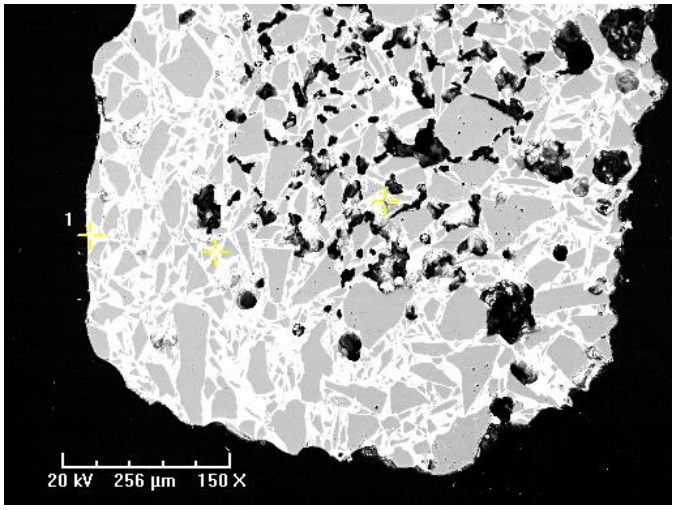


Figure F.152: Profile 2 of New Kingdom bead 2384-5, efflorescence.

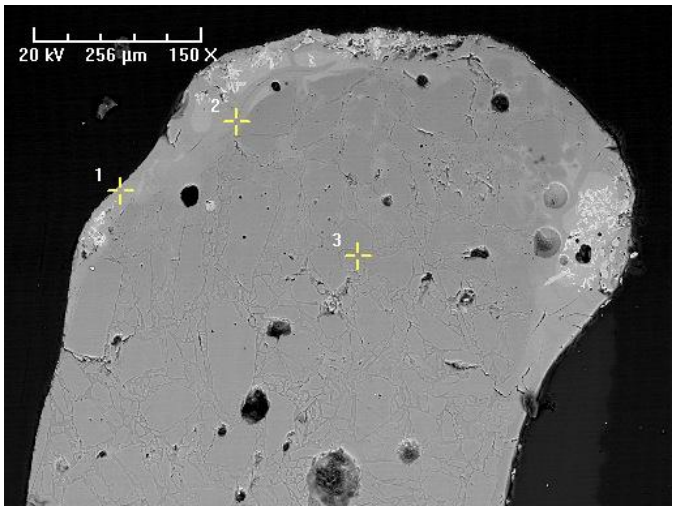


Figure F.153: Profile 1 of New Kingdom bead 2384-6, efflorescence.

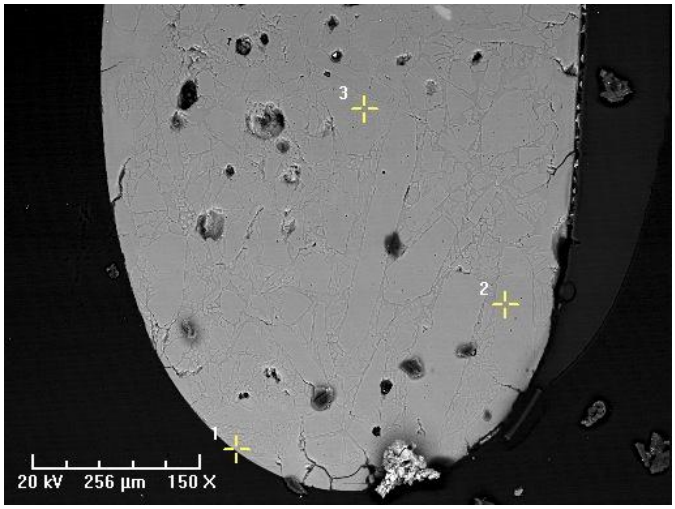


Figure F.154: Profile 2 of New Kingdom bead 2384-6, efflorescence.

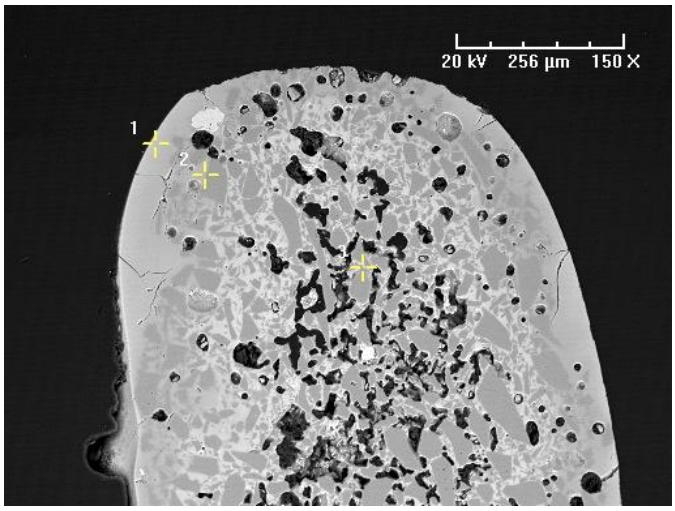


Figure F.155: Profile 1 of New Kingdom bead 2384-7, efflorescence.

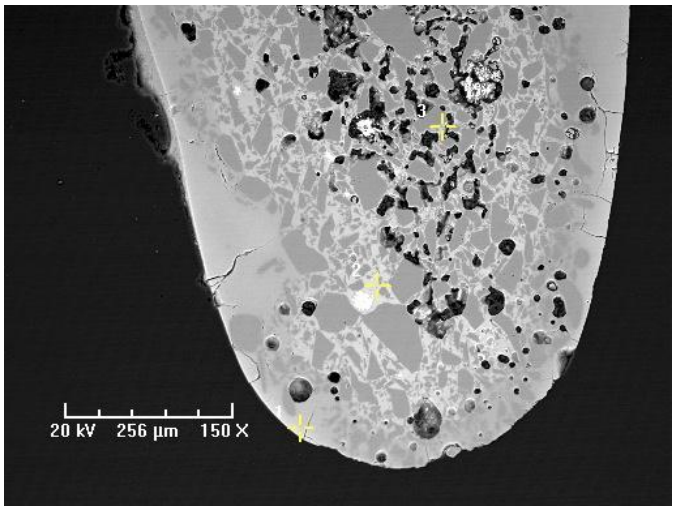


Figure F.156: Profile 2 of New Kingdom bead 2384-7, efflorescence.

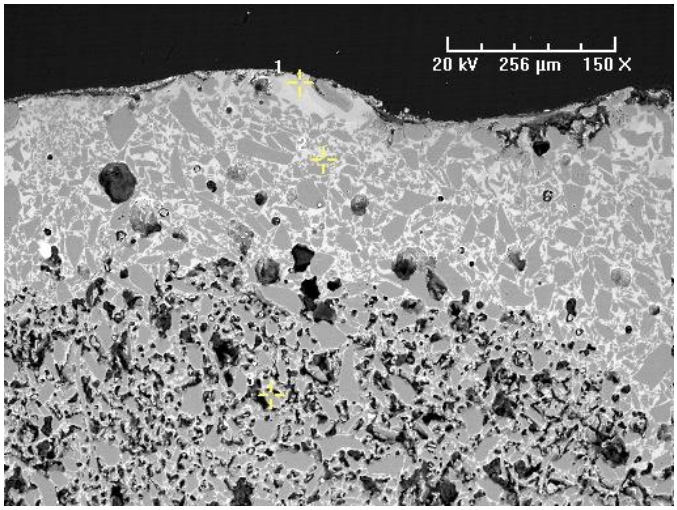


Figure F.157: Profile 1 of New Kingdom bead 2384-8, efflorescence.

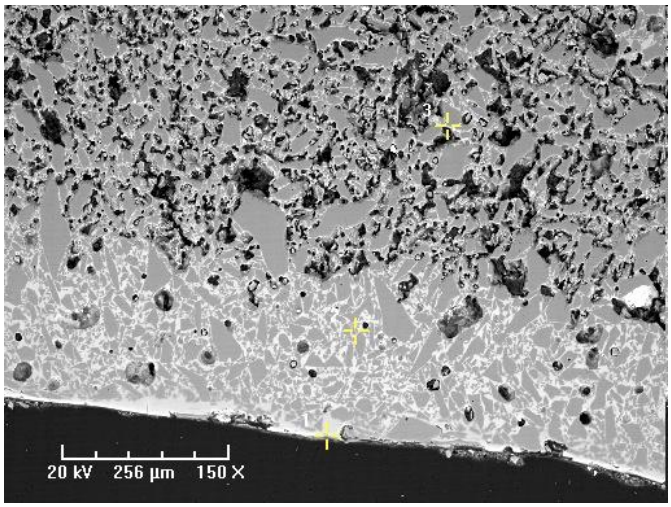


Figure F.158: Profile 2 of New Kingdom bead 2384-8, efflorescence.

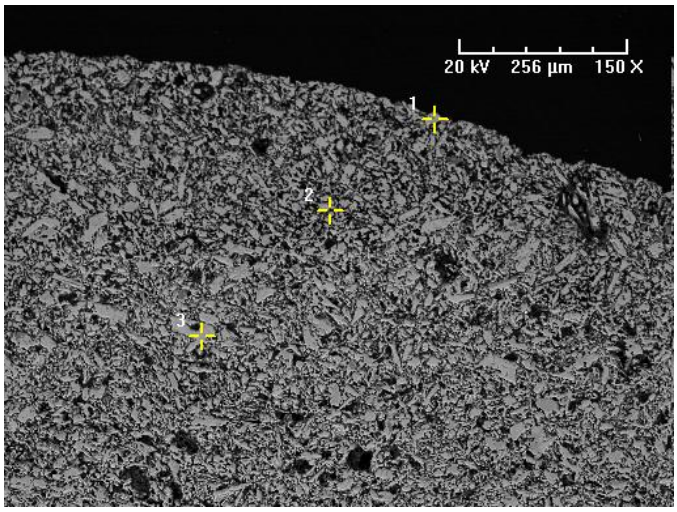


Figure F.159: Profile 1 of New Kingdom bead 2384-9, unknown.

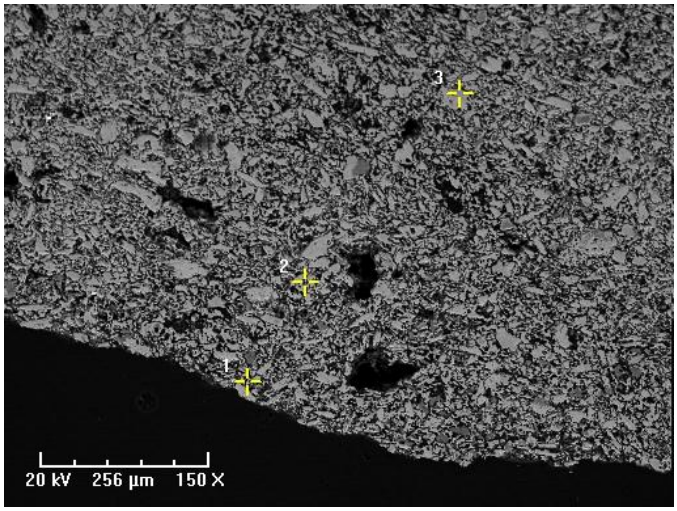


Figure F.160: Profile 2 of New Kingdom bead 2384-9, unknown.

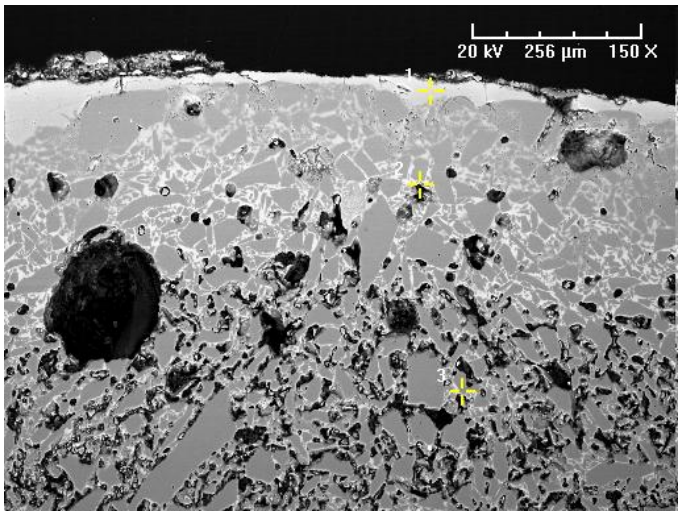


Figure F.161: Profile 1 of New Kingdom bead 2384-10, efflorescence.

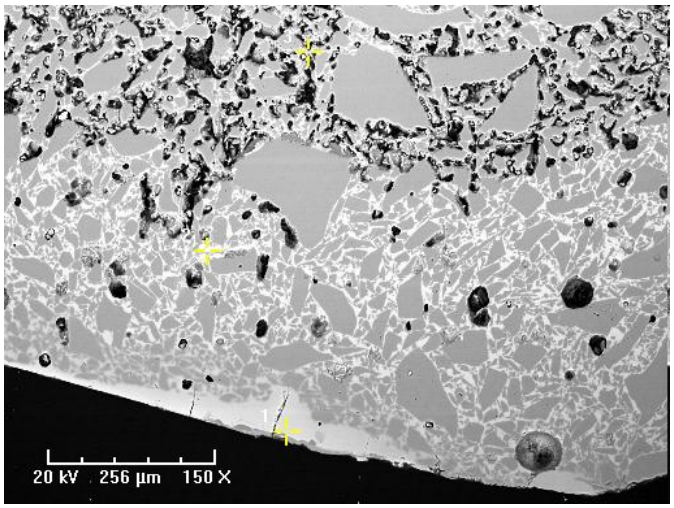


Figure F.162: Profile 2 of New Kingdom bead 2384-10, efflorescence.

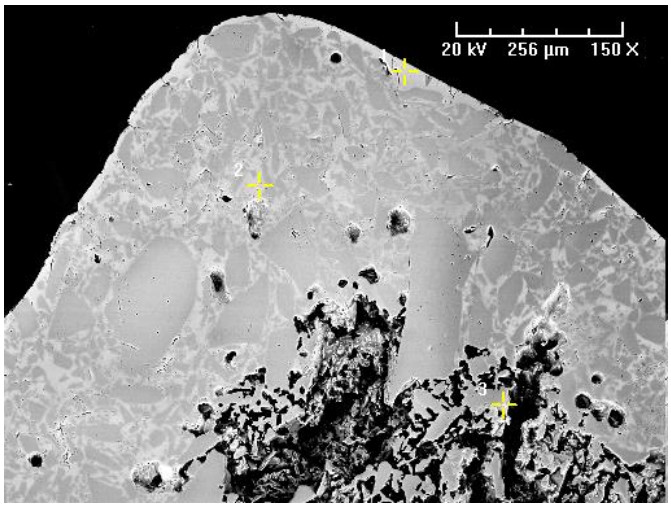


Figure F.163: Profile 1 of New Kingdom bead 2375-1, efflorescence.

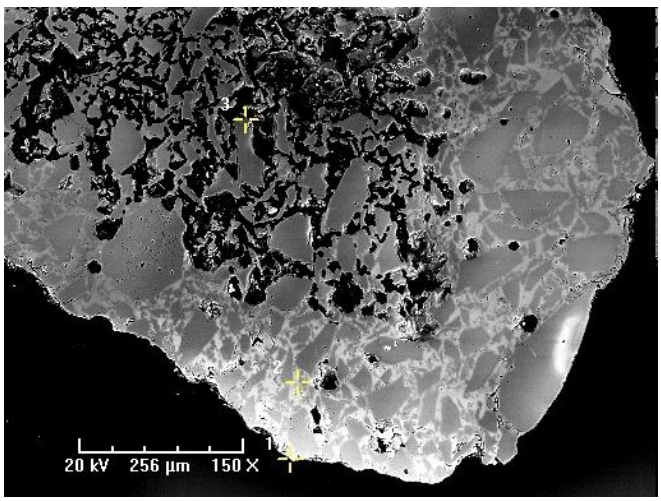


Figure F.164: Profile 2 of New Kingdom bead 2375-1, efflorescence.

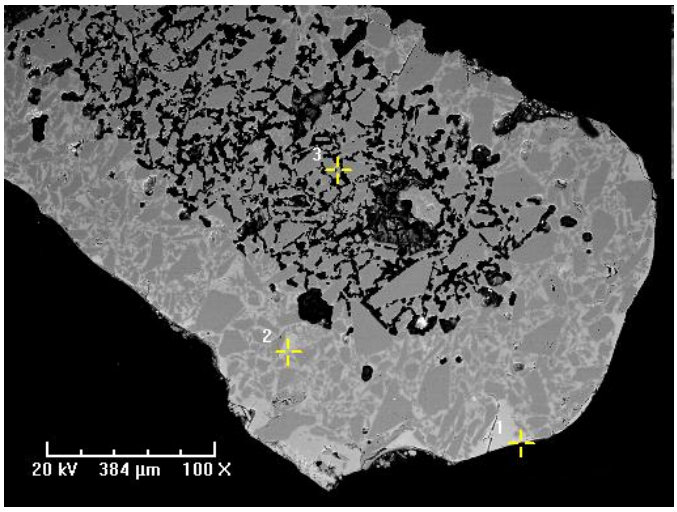


Figure F.165: Profile 1 of New Kingdom bead 2375-2, efflorescence.

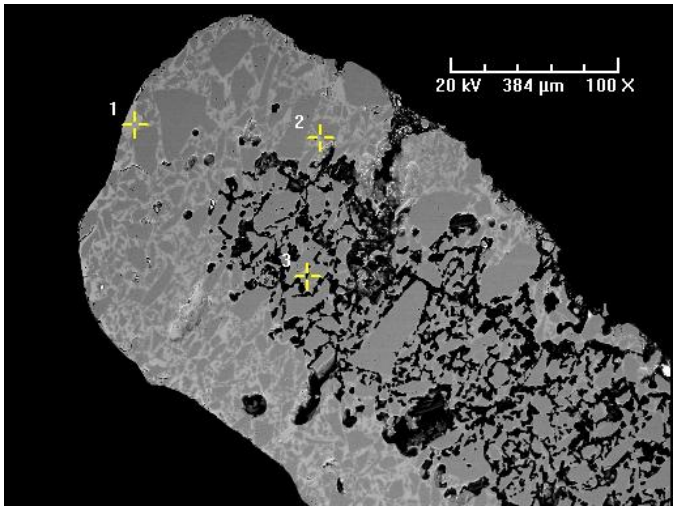


Figure F.166: Profile 2 of New Kingdom bead 2375-2, efflorescence.

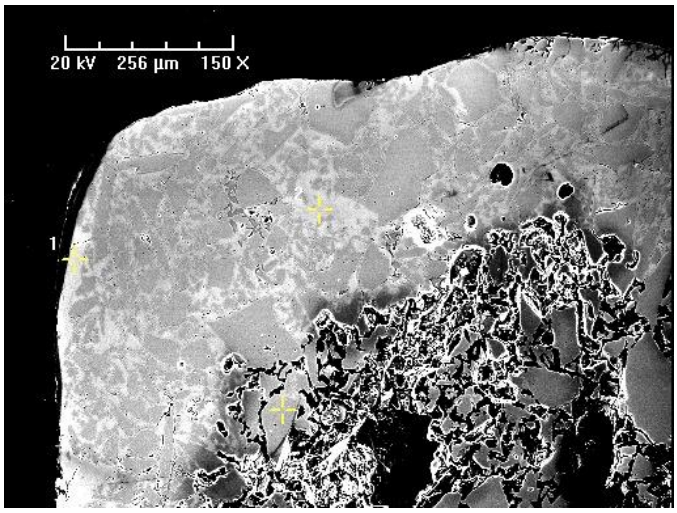


Figure F.167: Profile 1 of New Kingdom bead 2375-3, efflorescence.

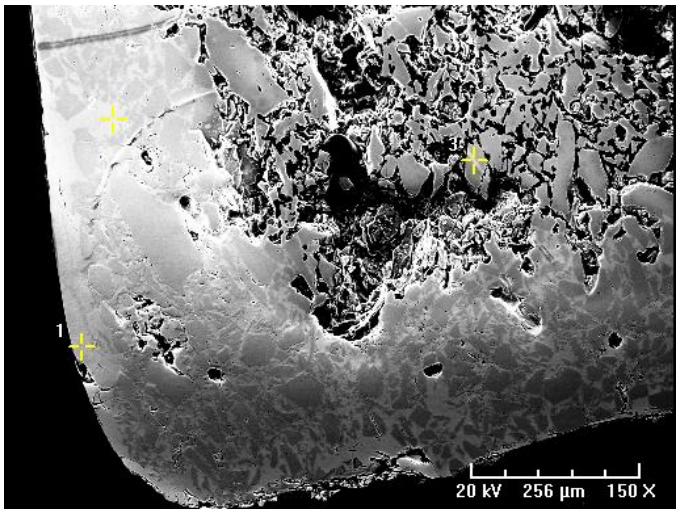


Figure F.168: Profile 2 of New Kingdom bead 2375-3, efflorescence.

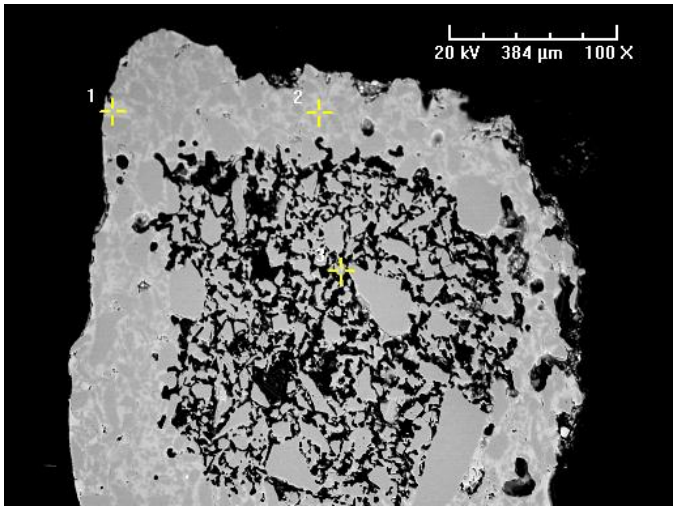


Figure F.169: Profile 1 of New Kingdom bead 2375-4, cementation.

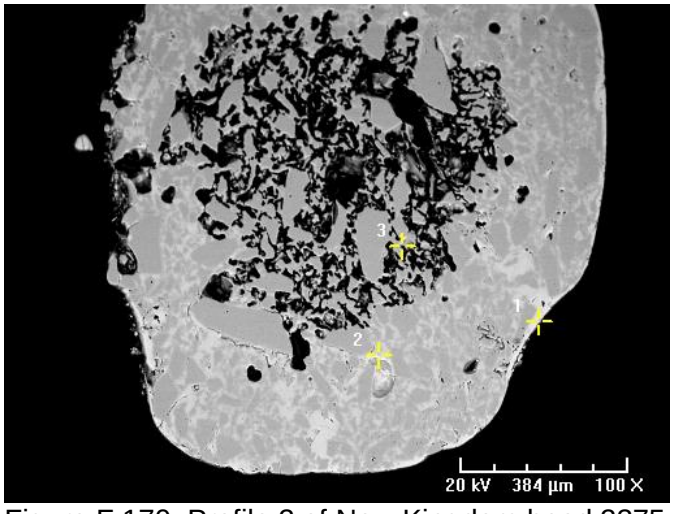


Figure F.170: Profile 2 of New Kingdom bead 2375-4, cementation.

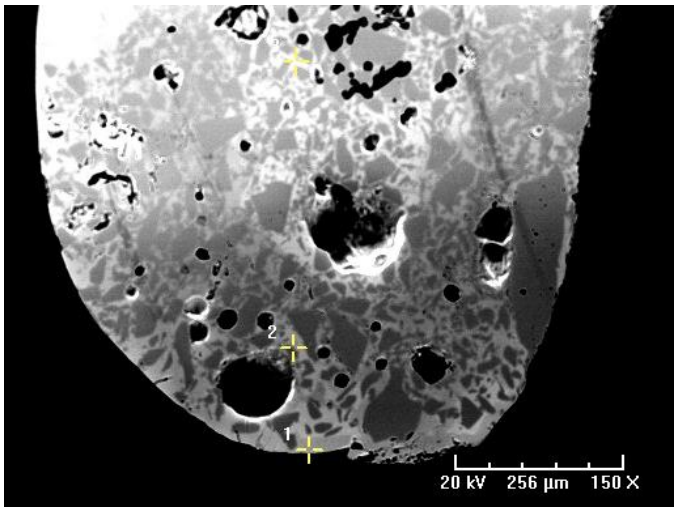


Figure F.171: Profile 1 of New Kingdom bead 2375-5, efflorescence.

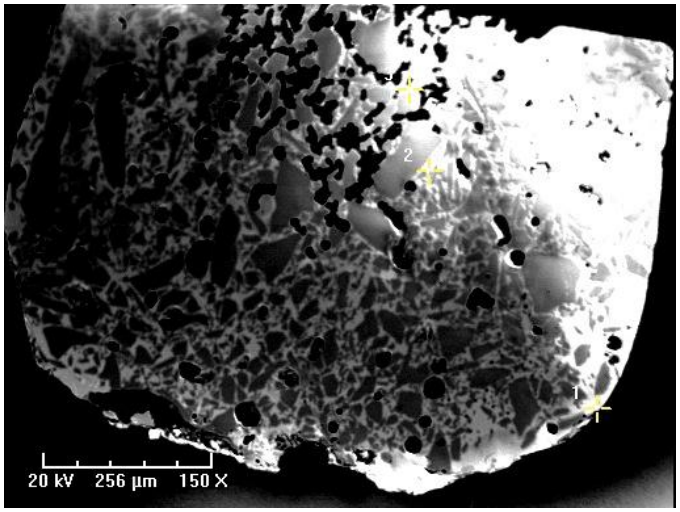


Figure F.172: Profile 2 of New Kingdom bead 2375-5, efflorescence.

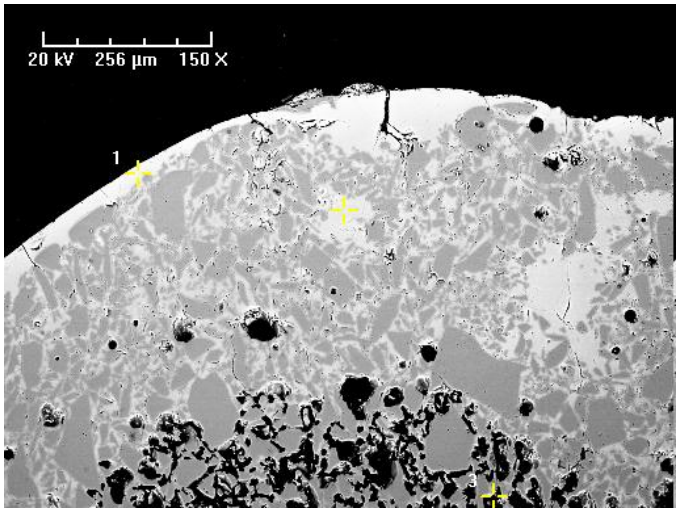


Figure F.173: Profile 1 of New Kingdom bead 2375-6, efflorescence.

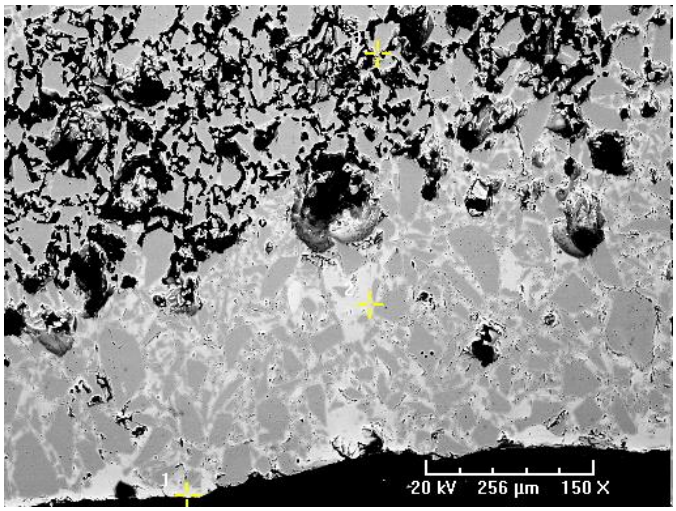


Figure F.174: Profile 2 of New Kingdom bead 2375-6, efflorescence.

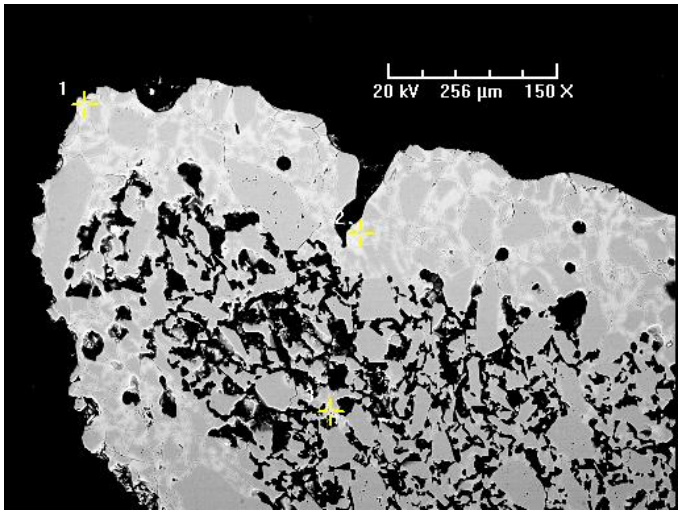


Figure F.175: Profile 1 of New Kingdom bead 2375-7, efflorescence.

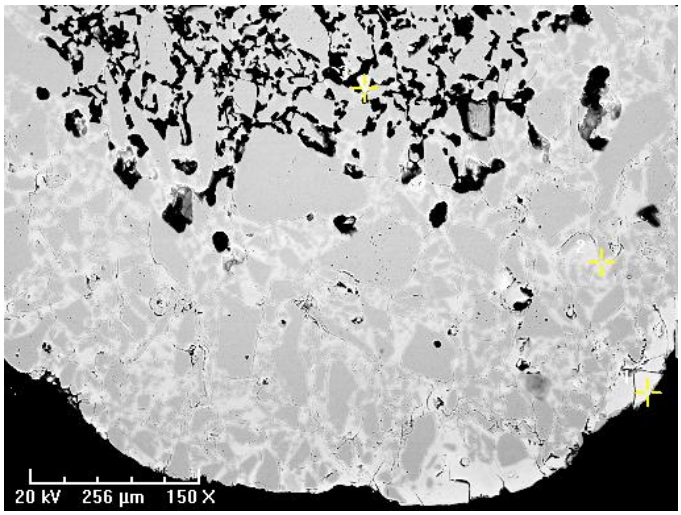


Figure F.176: Profile 2 of New Kingdom bead 2375-7, efflorescence.

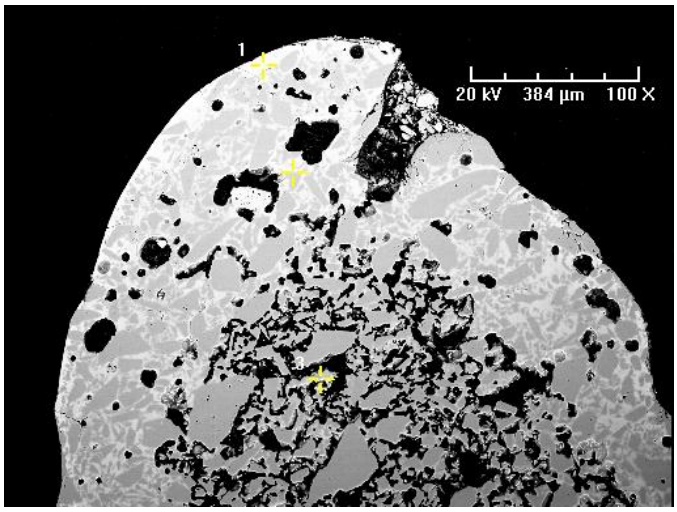


Figure F.177: Profile 1 of New Kingdom bead 2375-8, efflorescence.

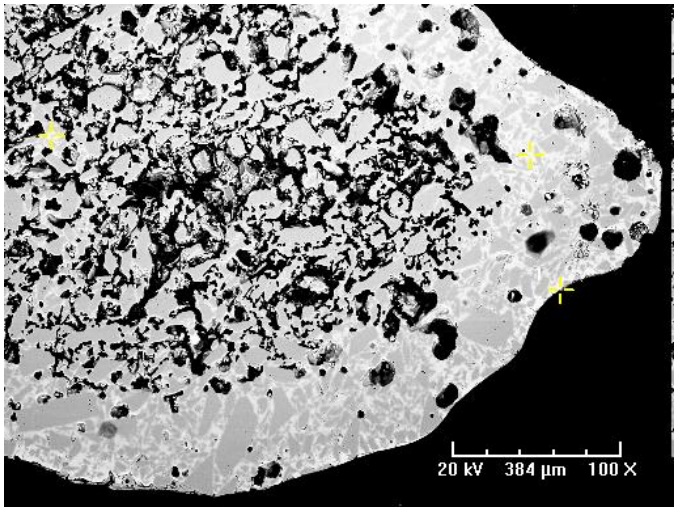


Figure F.178: Profile 2 of New Kingdom bead 2375-8, efflorescence.

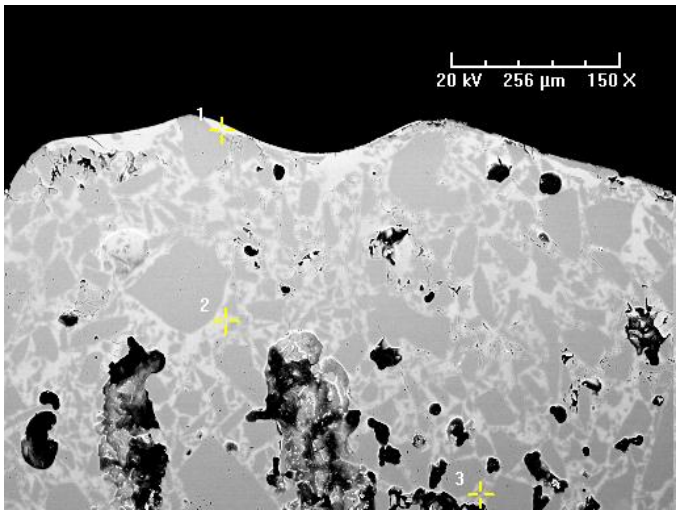


Figure F.179: Profile 1 of New Kingdom bead 2375-9, efflorescence.

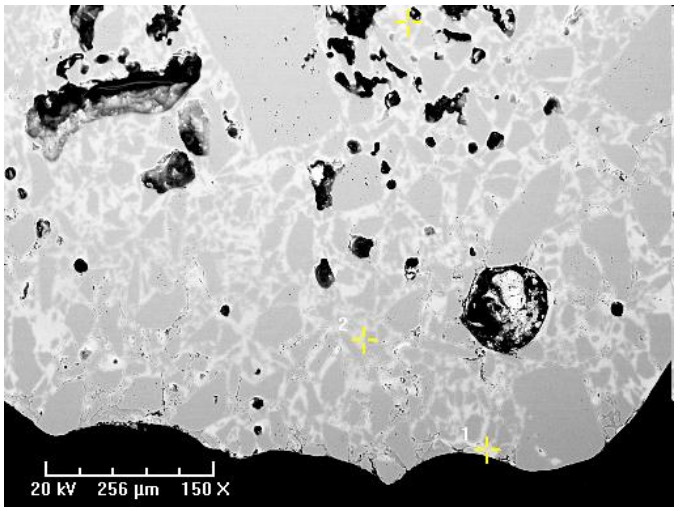


Figure F.180: Profile 2 of New Kingdom bead 2375-9, efflorescence.

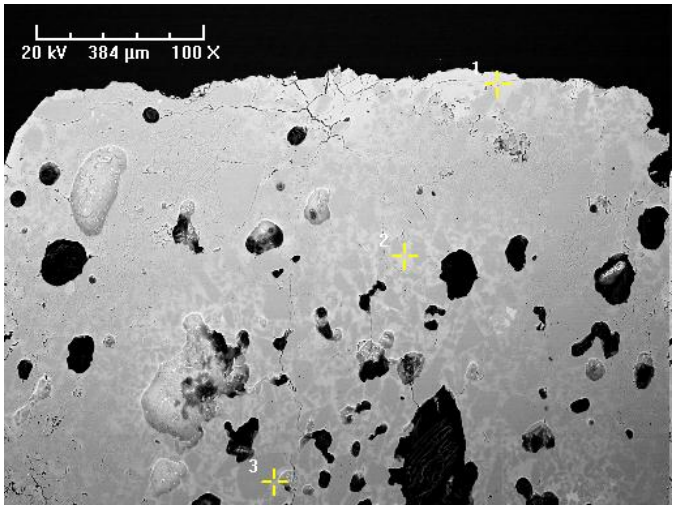


Figure F.181: Profile 1 of New Kingdom bead 2375-10, efflorescence.

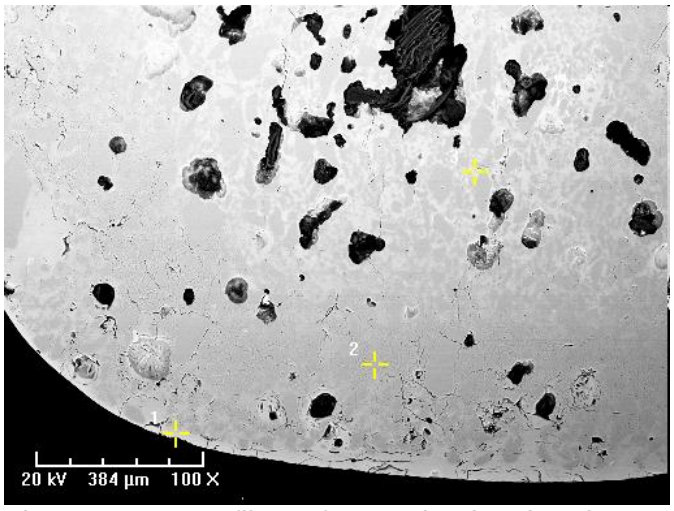


Figure F.182: Profile 2 of New Kingdom bead 2375-10, efflorescence.

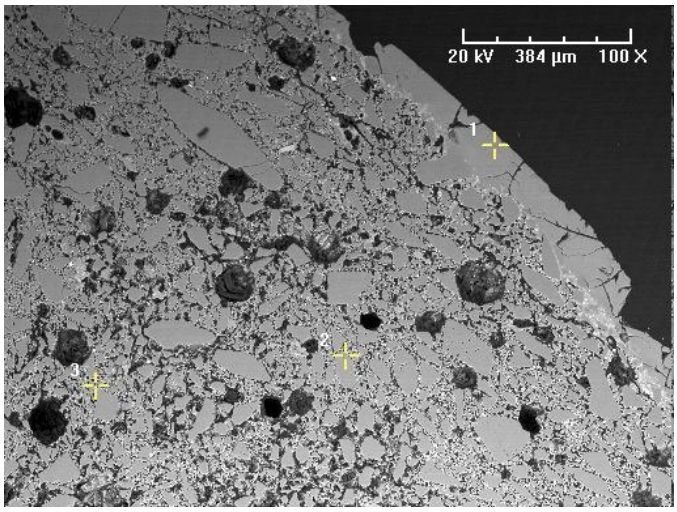


Figure F.183: Profile 1 of New Kingdom bead 2389-1, efflorescence.

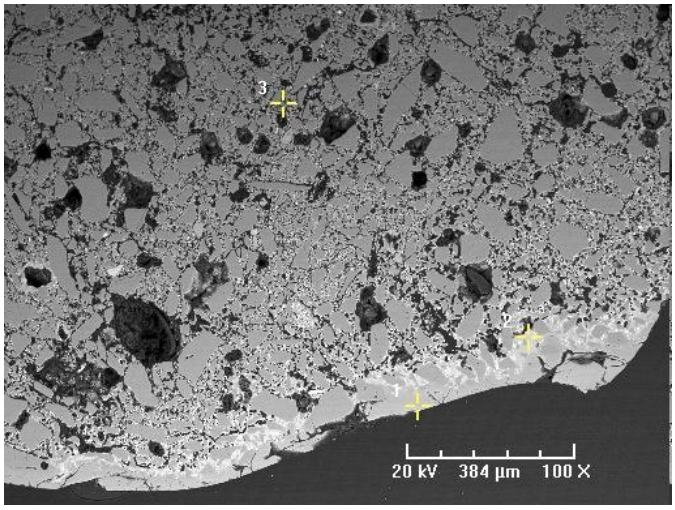


Figure F.184: Profile 2 of New Kingdom bead 2389-1, efflorescence.

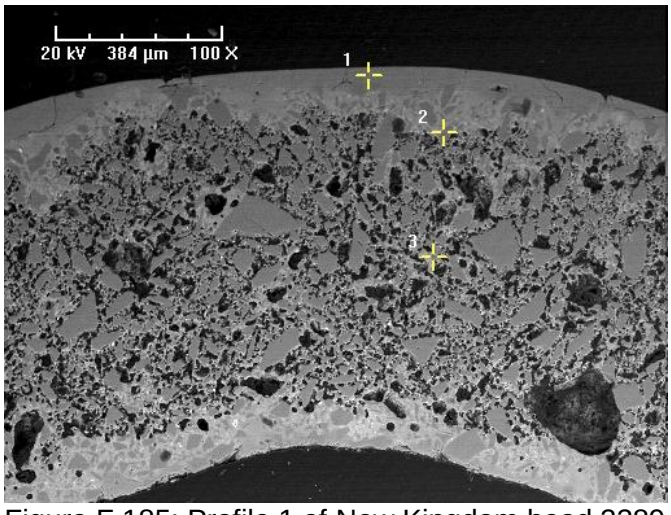


Figure F.185: Profile 1 of New Kingdom bead 2389-2, efflorescence.

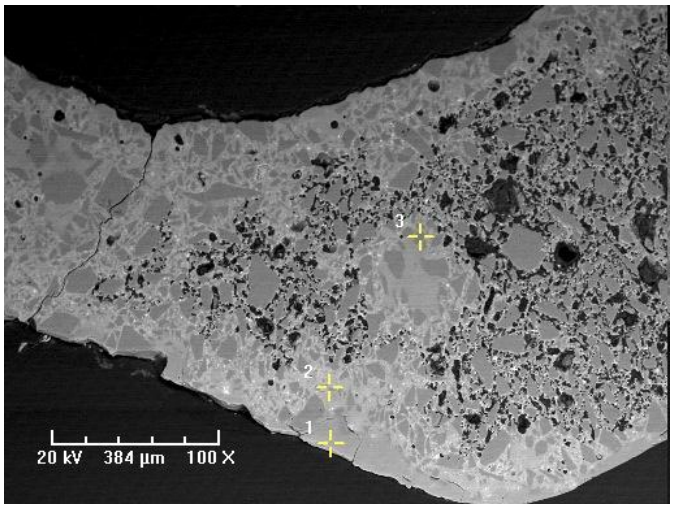


Figure F.186: Profile 2 of New Kingdom bead 2389-2, efflorescence.

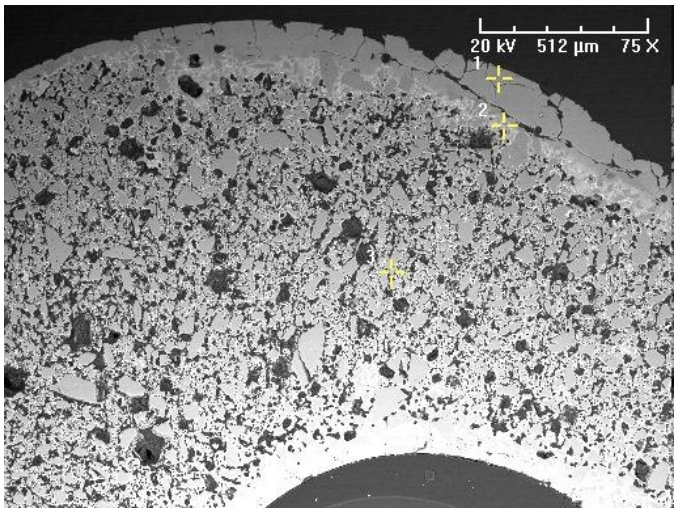


Figure F.187: Profile 1 of New Kingdom bead 2389-3, efflorescence.

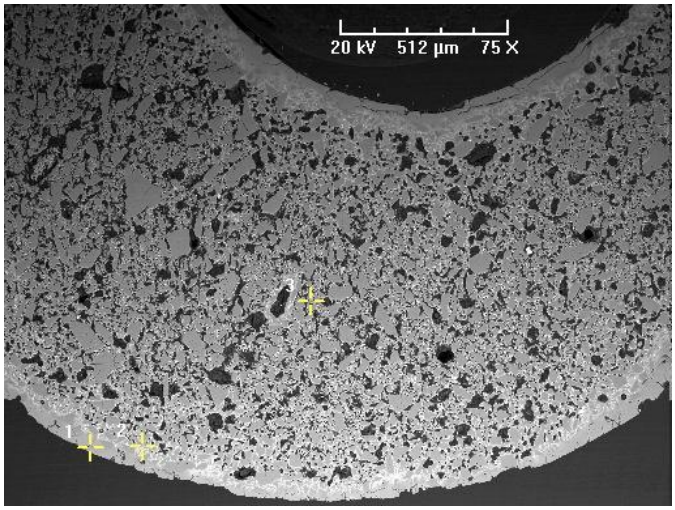


Figure F.188: Profile 2 of New Kingdom bead 2389-3, efflorescence.

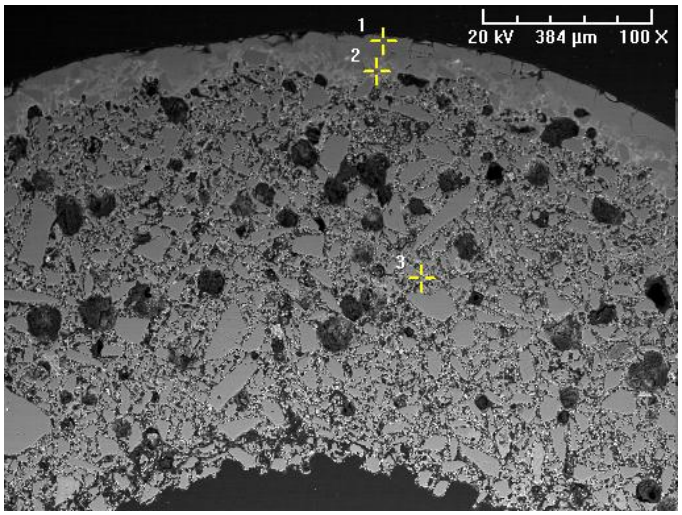


Figure F.189: Profile 1 of New Kingdom bead 2389-4, efflorescence.

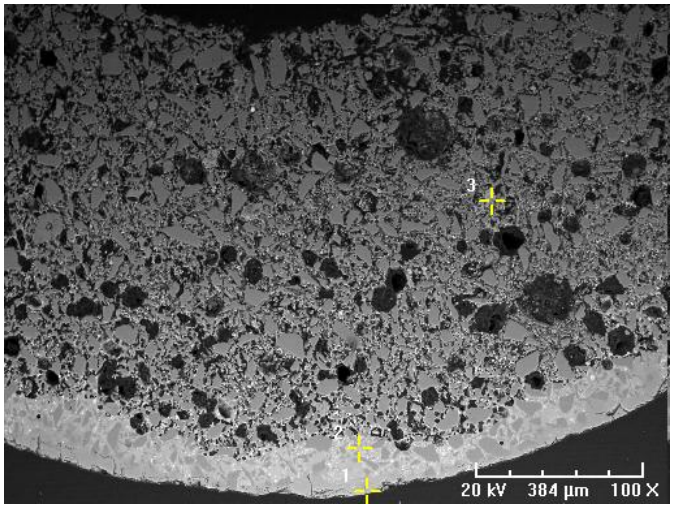


Figure F.190: Profile 2 of New Kingdom bead 2389-4, efflorescence.

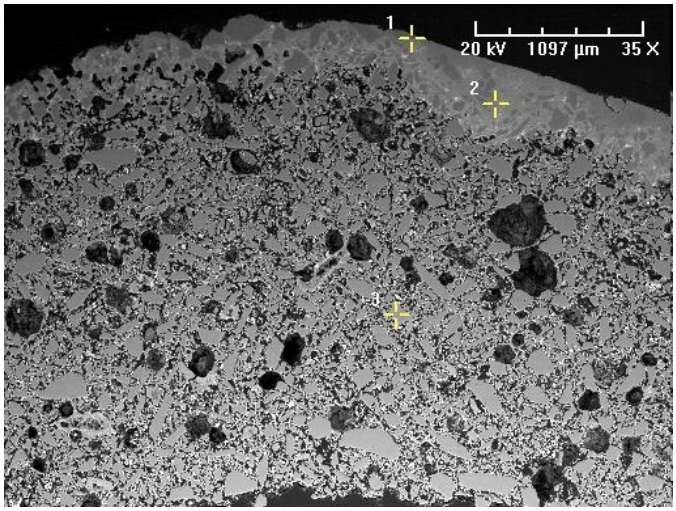


Figure F.191: Profile 1 of New Kingdom bead 2389-5, efflorescence.

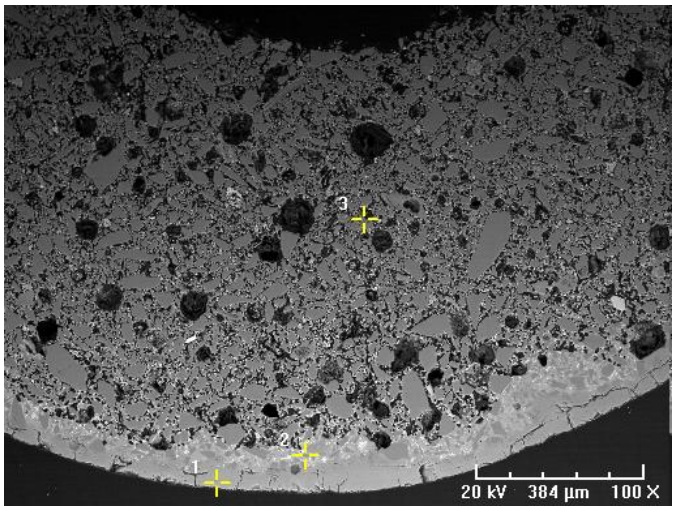


Figure F.192: Profile 2 of New Kingdom bead 2389-5, efflorescence.

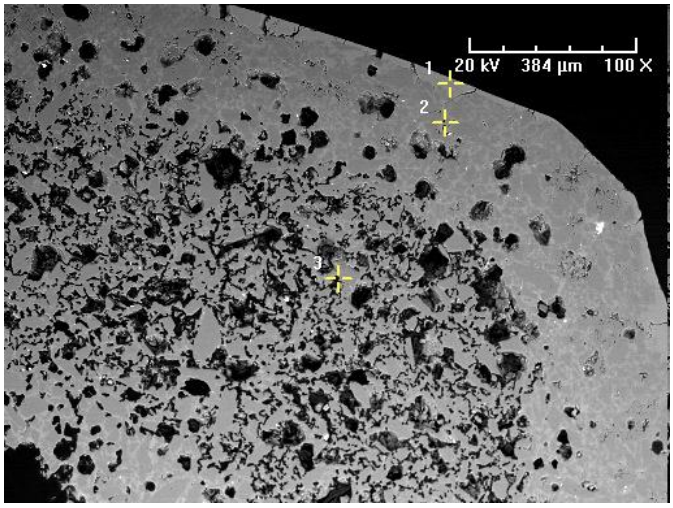


Figure F.193: Profile 1 of New Kingdom bead 2389-6, efflorescence.

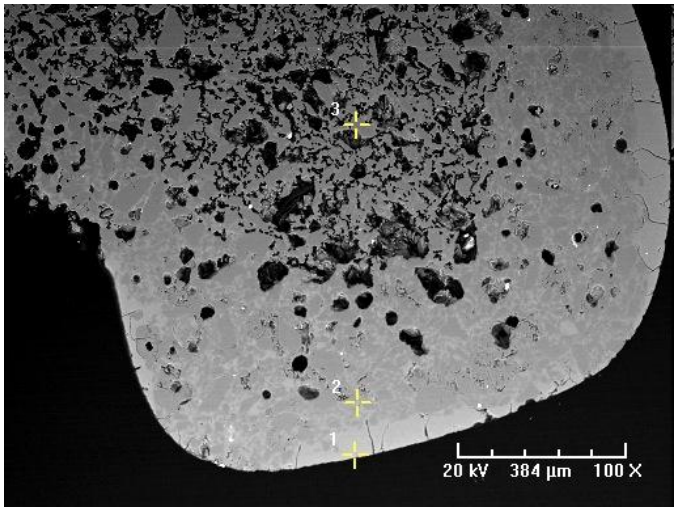


Figure F.194: Profile 2 of New Kingdom bead 2389-6, efflorescence.

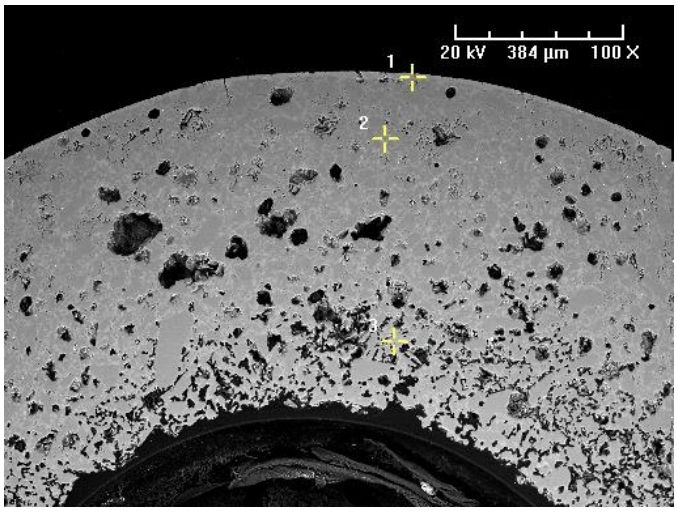


Figure F.195: Profile 1 of New Kingdom bead 2389-7, efflorescence.

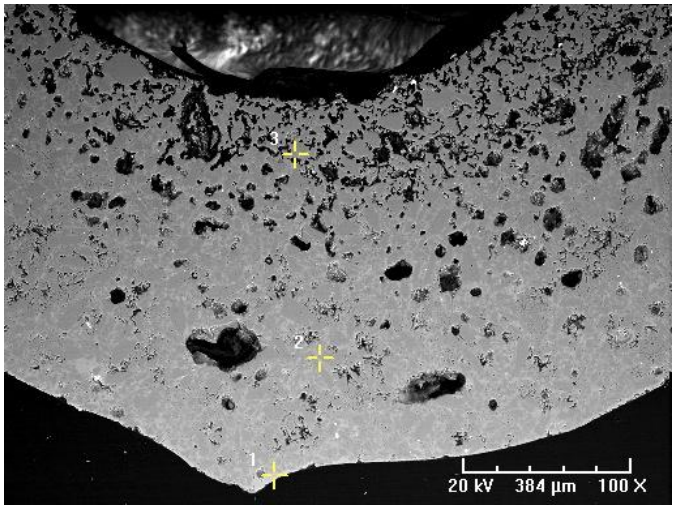


Figure F.196: Profile 2 of New Kingdom bead 2389-7, efflorescence.

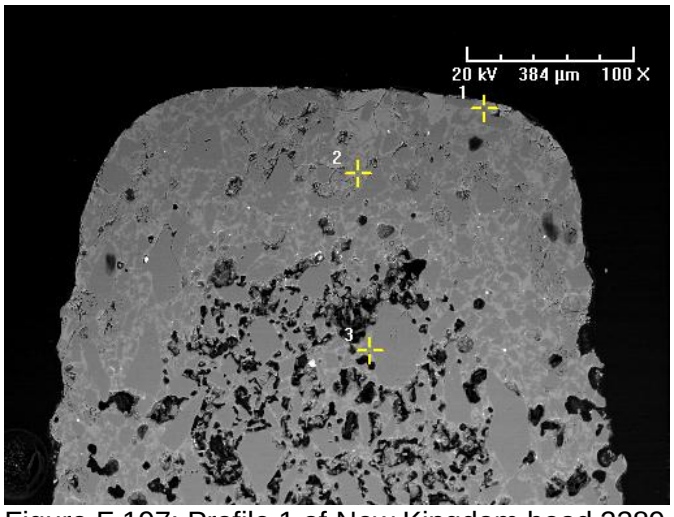


Figure F.197: Profile 1 of New Kingdom bead 2389-8, efflorescence.

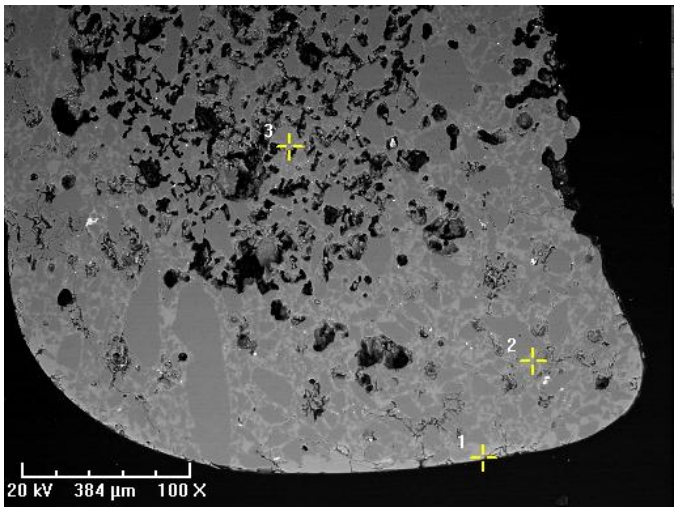


Figure F.198: Profile 2 of New Kingdom bead 2389-8, efflorescence.

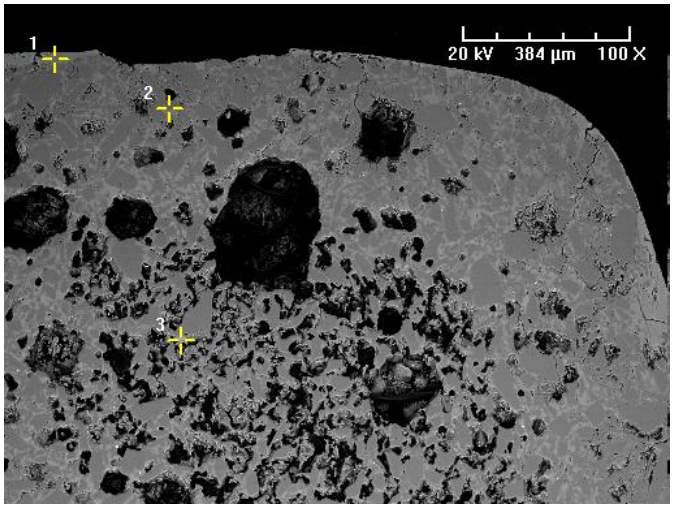


Figure F.199: Profile 1 of New Kingdom bead 2389-9, efflorescence.

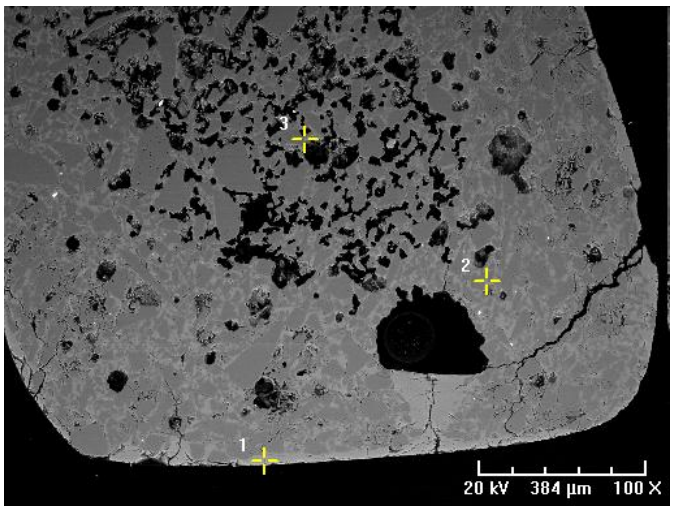


Figure F.200: Profile 2 of New Kingdom bead 2389-9, efflorescence.

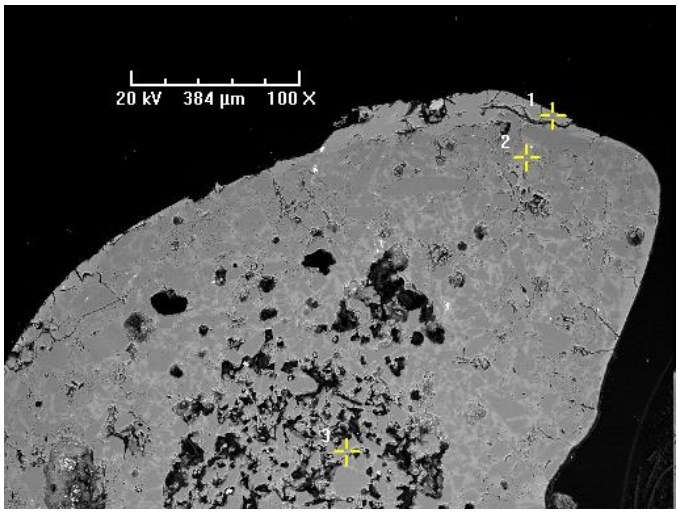


Figure F.201: Profile 1 of New Kingdom bead 2389-10, efflorescence.

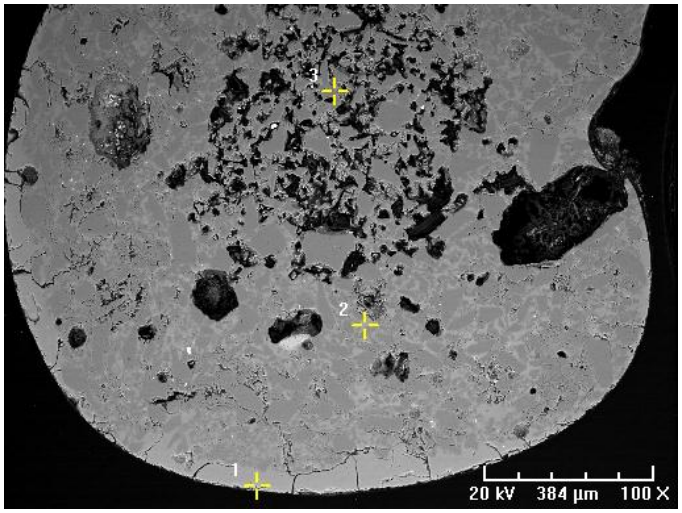


Figure F.202: Profile 2 of New Kingdom bead 2389-10, efflorescence.

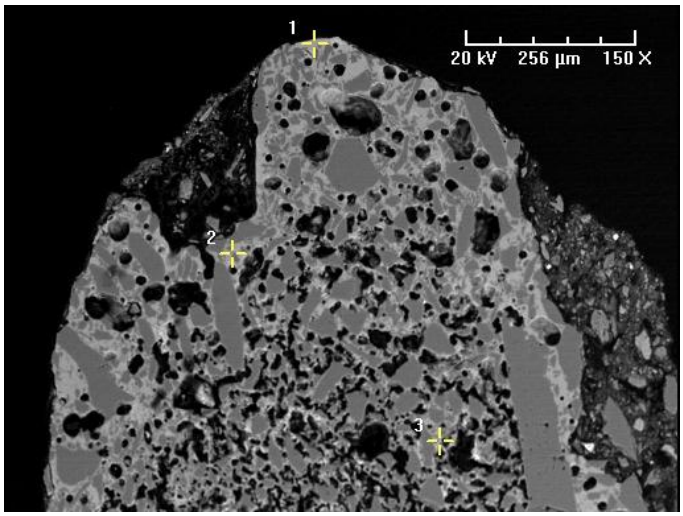


Figure F.203: Profile 1 of New Kingdom bead 2344-1, cementation.

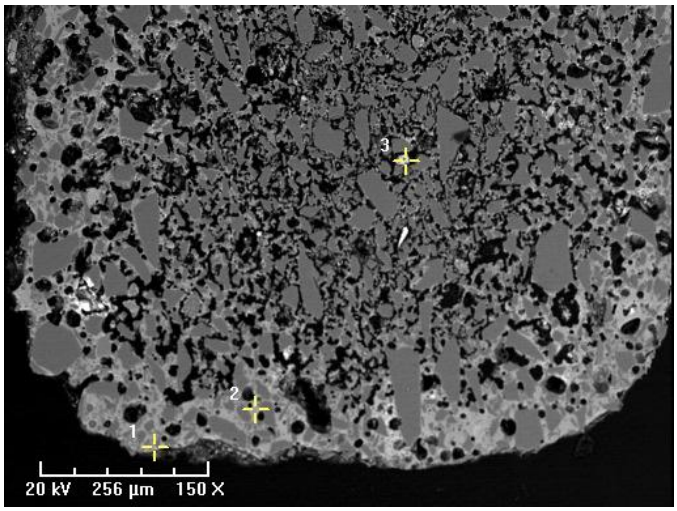


Figure F.204: Profile 2 of New Kingdom bead 2344-1, cementation.

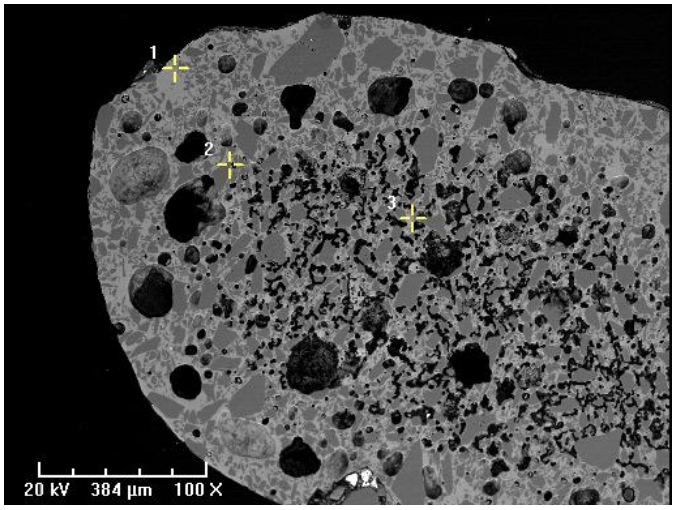


Figure F.205: Profile 1 of New Kingdom bead 2344-2, efflorescence.

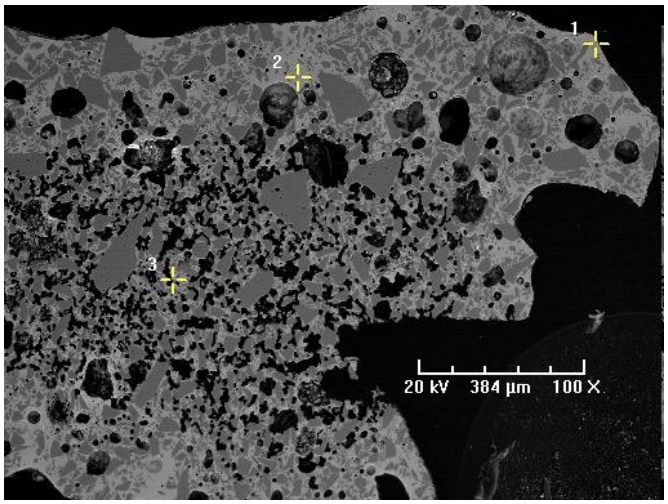


Figure F.206: Profile 2 of New Kingdom bead 2344-2, efflorescence.

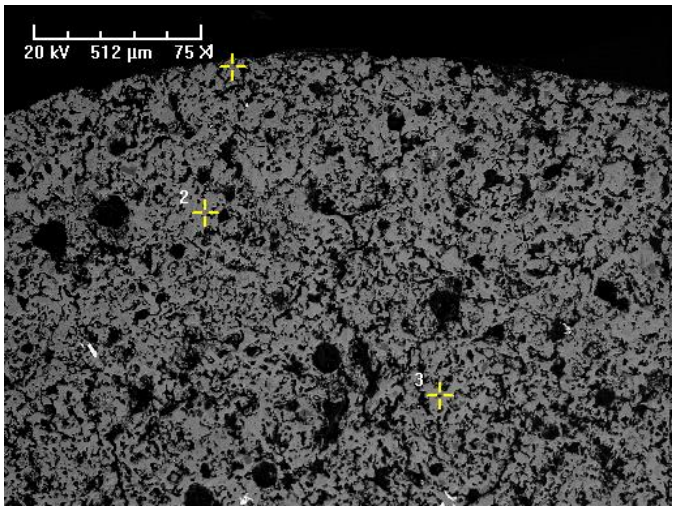


Figure F.207: Profile 1 of New Kingdom bead 2344-3, unknown.

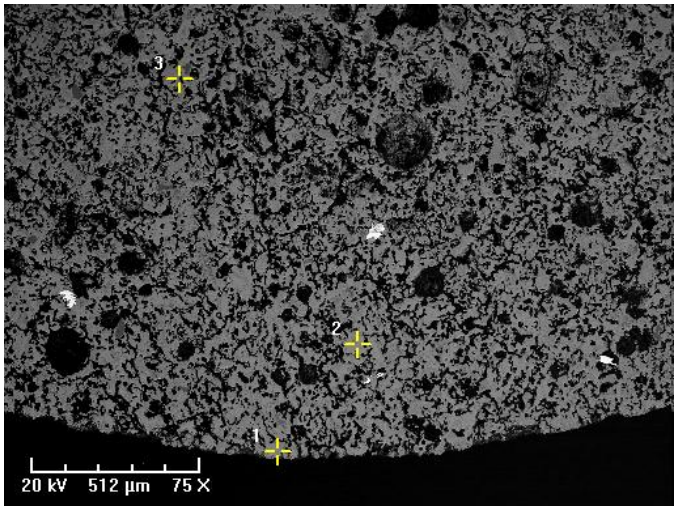


Figure F.208: Profile 2 of New Kingdom bead 2344-3, unknown.

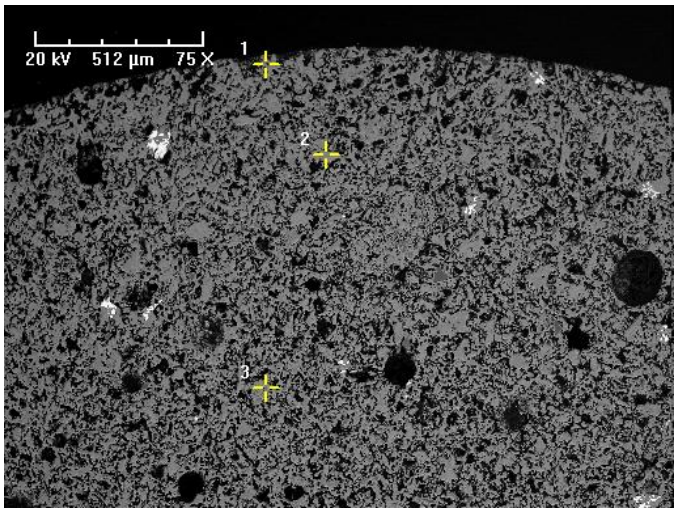


Figure F.209: Profile 1 of New Kingdom bead 2344-4, unknown.

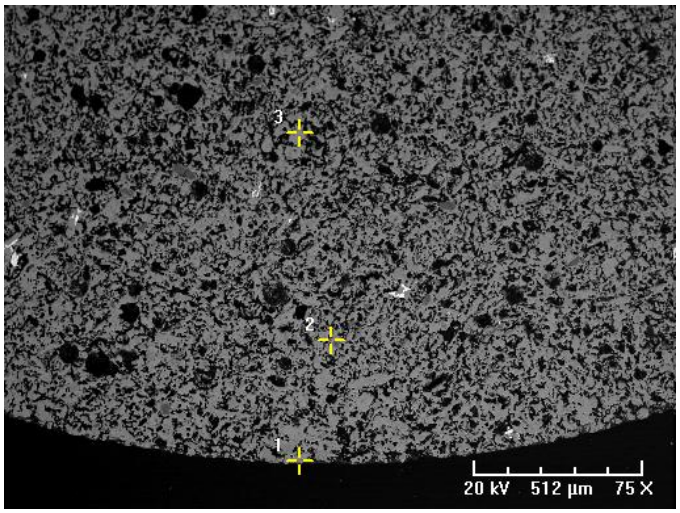


Figure F.210: Profile 2 of New Kingdom bead 2344-4, unknown.

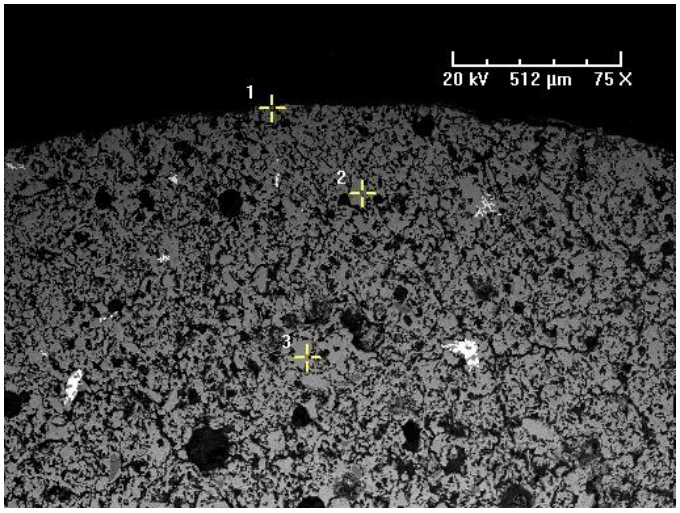


Figure F.211: Profile 1 of New Kingdom bead 2344-5, unknown.

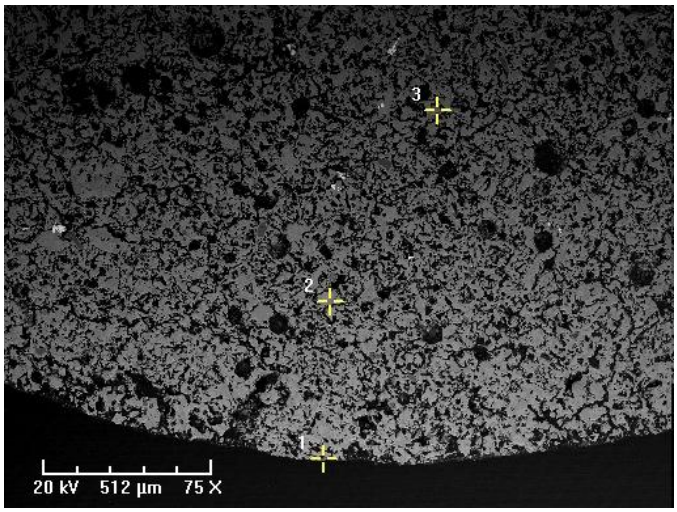


Figure F.212: Profile 2 of New Kingdom bead 2344-5, unknown.

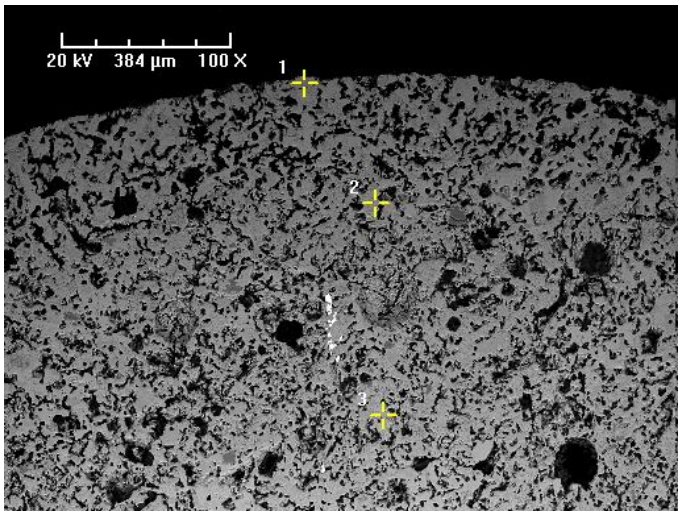


Figure F.213: Profile 1 of New Kingdom bead 2344-6, unknown.

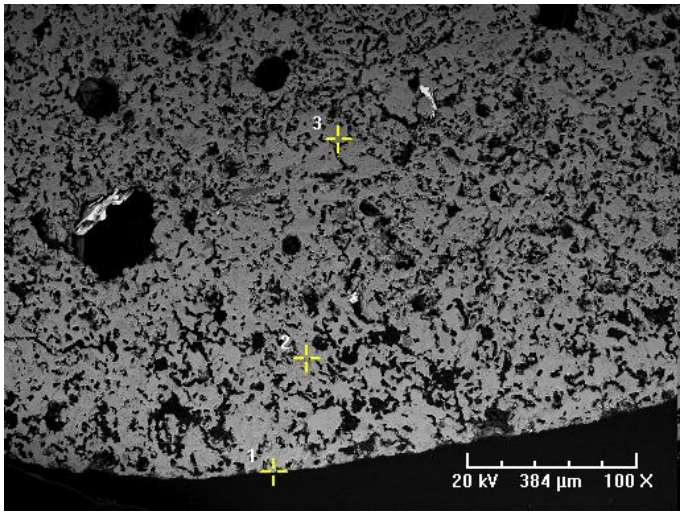


Figure F.214: Profile 2 of New Kingdom bead 2344-6, unknown.

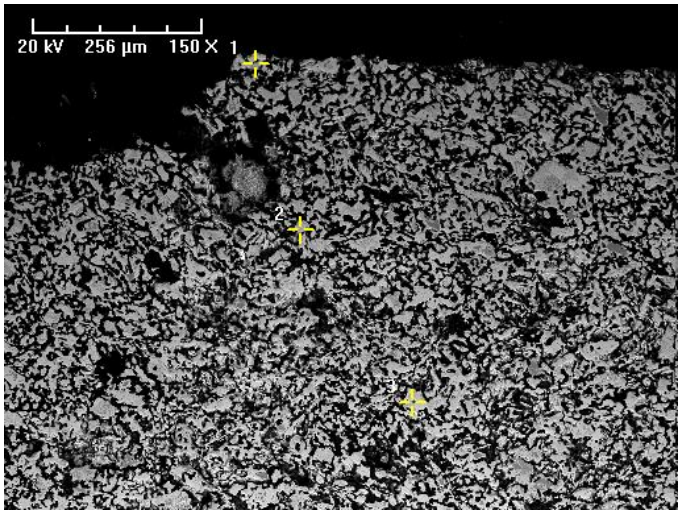


Figure F.215: Profile 1 of New Kingdom bead 2344-7, unknown.

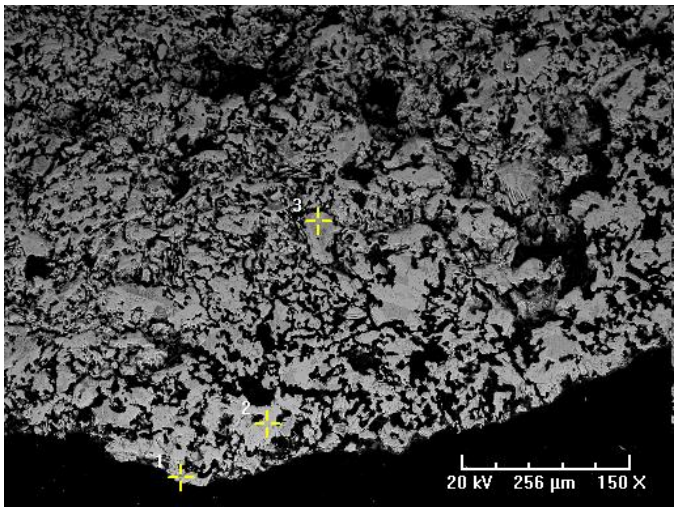


Figure F.216: Profile 2 of New Kingdom bead 2344-7, unknown.

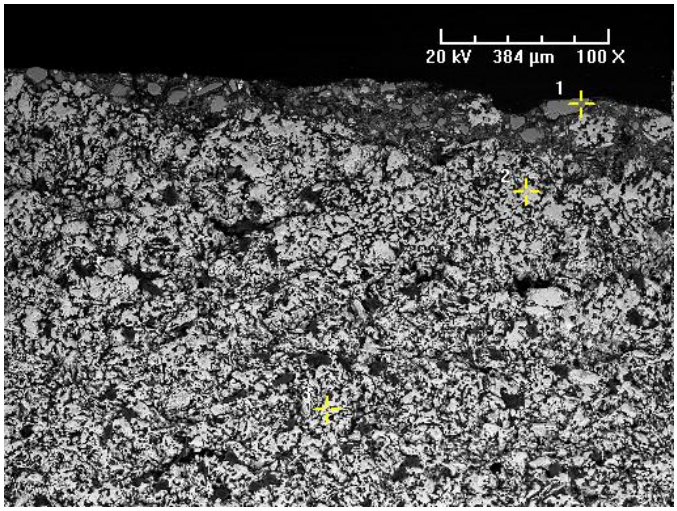


Figure F.217: Profile 1 of New Kingdom bead 2344-8, unknown.

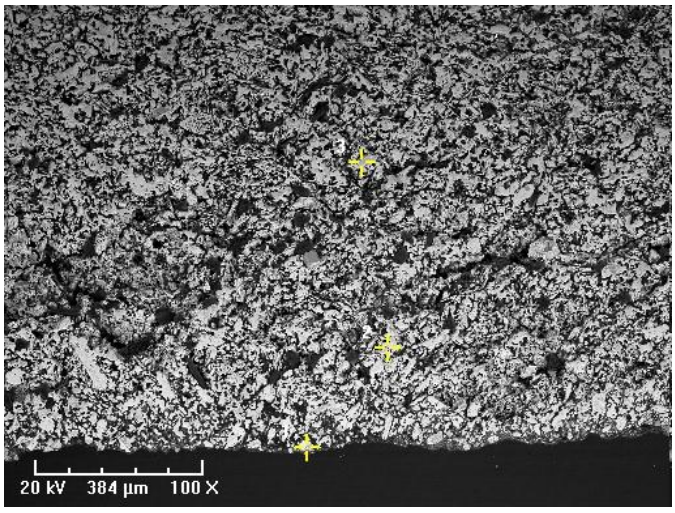


Figure F.218: Profile 2 of New Kingdom bead 2344-8, unknown.

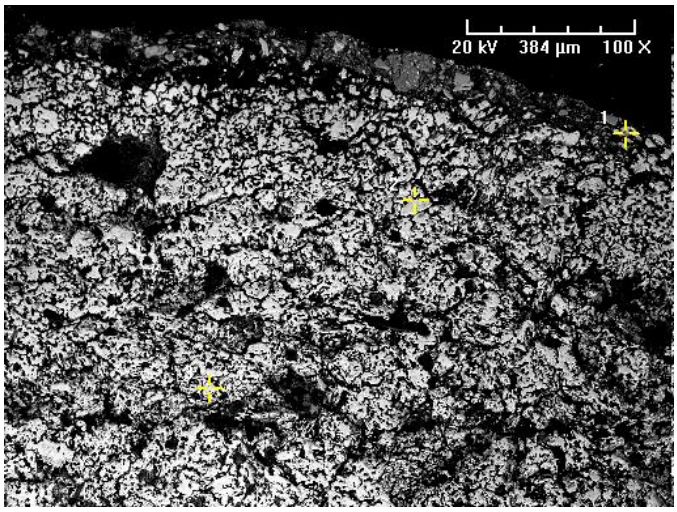


Figure F.219: Profile 1 of New Kingdom bead 2344-9, unknown.

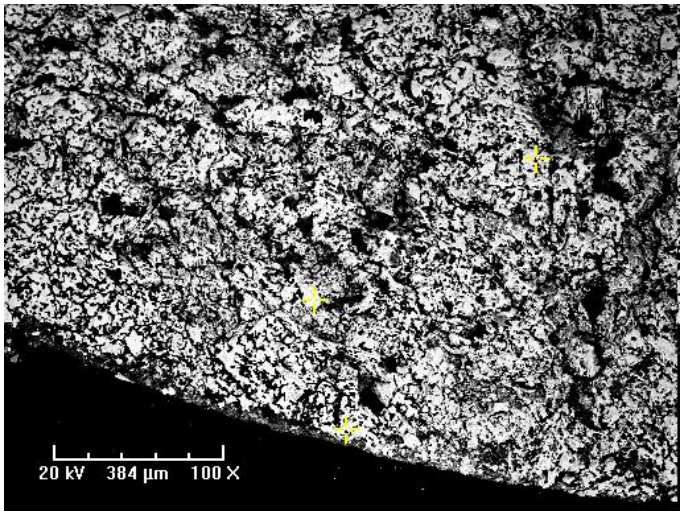


Figure F.220: Profile 2 of New Kingdom bead 2344-9, unknown.

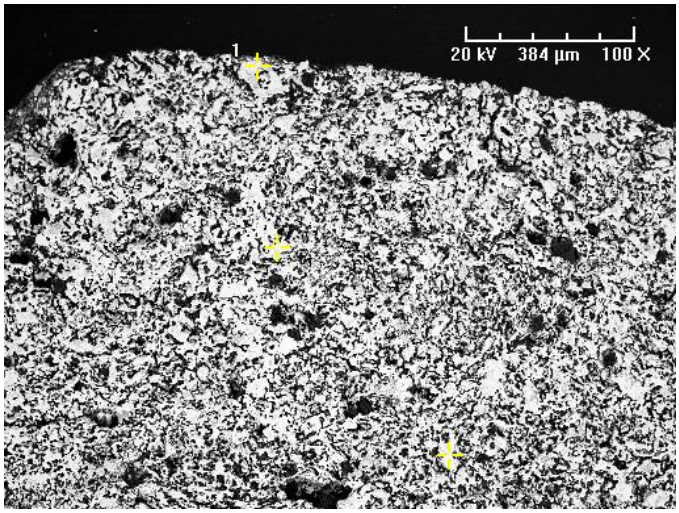


Figure F.221: Profile 1 of New Kingdom bead 2344-10, unknown.

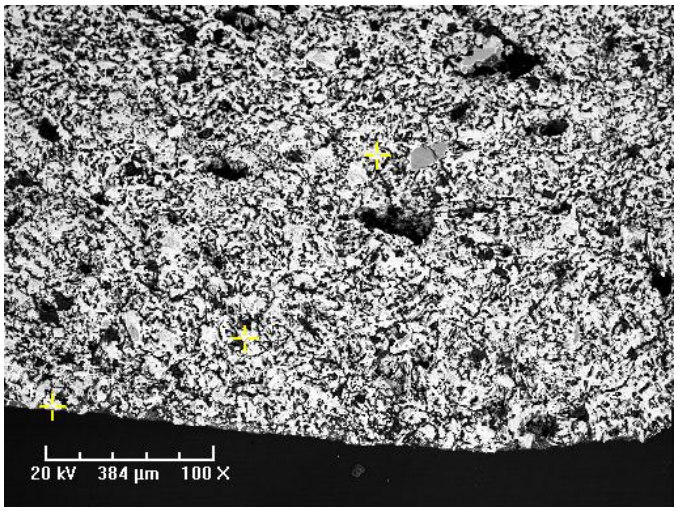


Figure F.222: Profile 2 of New Kingdom bead 2344-10, unknown.

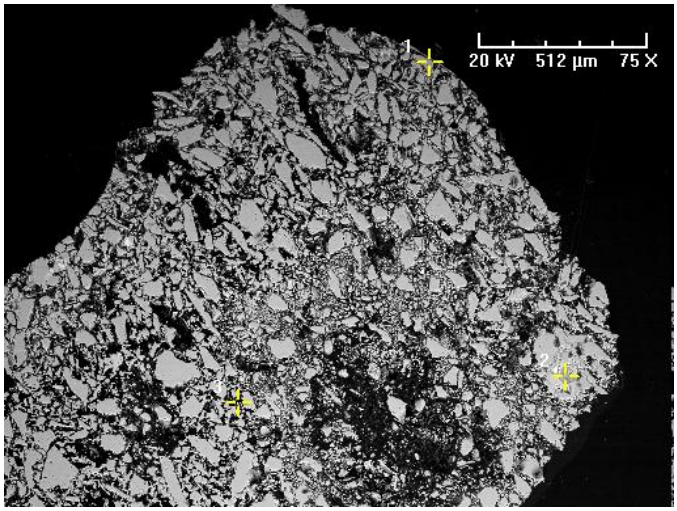


Figure F.223: Profile 1 of New Kingdom bead 2377-1, unknown.

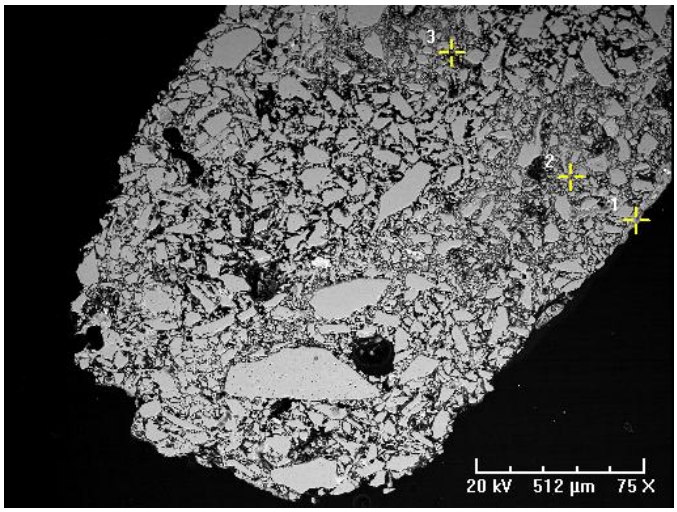


Figure F.224: Profile 2 of New Kingdom bead 2377-1, unknown.

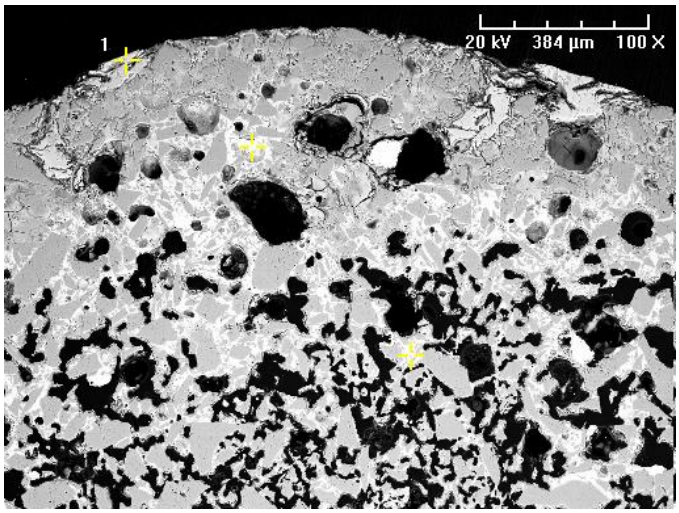


Figure F.225: Profile 1 of New Kingdom bead 2377-2, efflorescence.

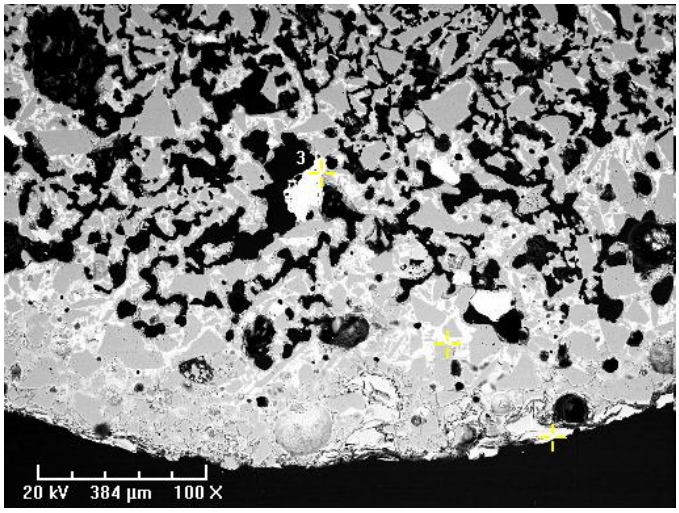


Figure F.226: Profile 2 of New Kingdom bead 2377-2, efflorescence.

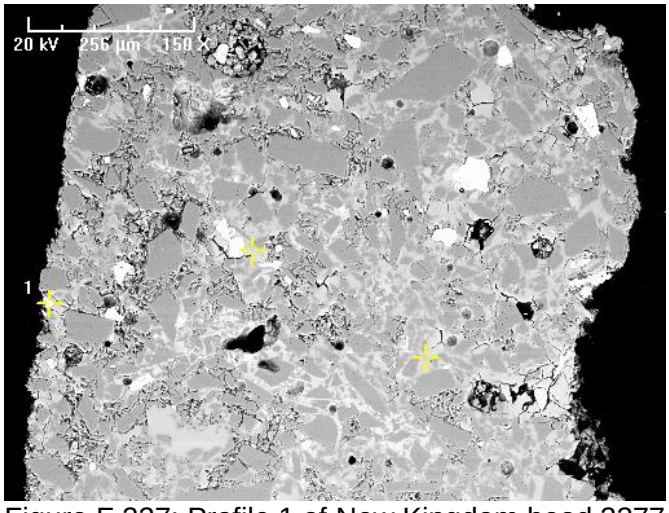


Figure F.227: Profile 1 of New Kingdom bead 2377-3, efflorescence.

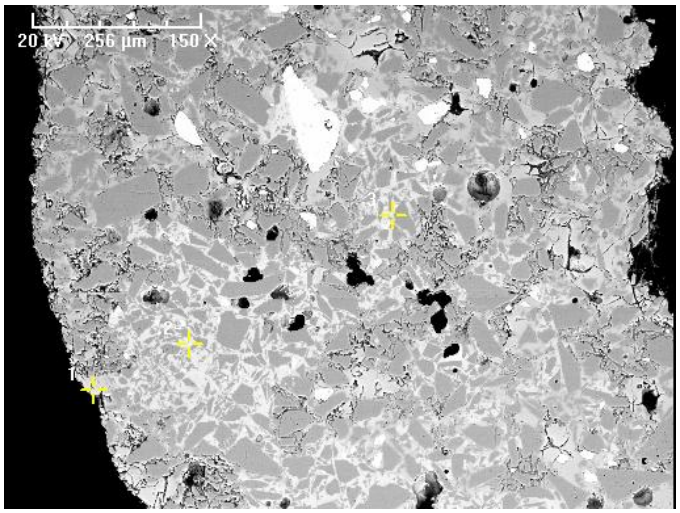


Figure F.228: Profile 2 of New Kingdom bead 2377-3, efflorescence.

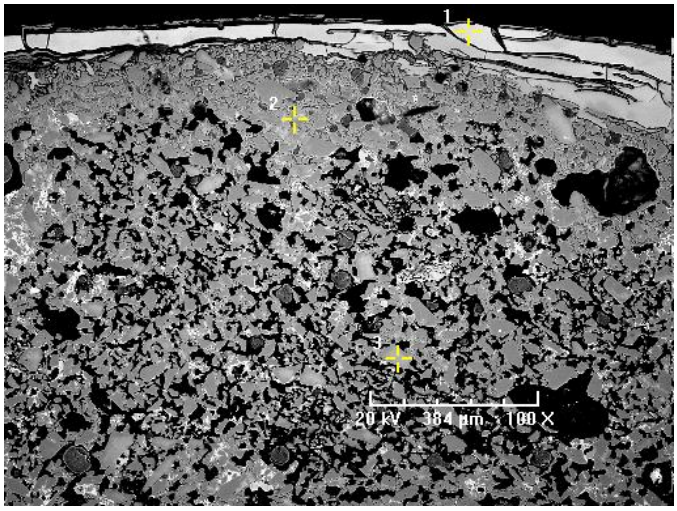


Figure F.229: Profile 1 of New Kingdom bead 2377-4, efflorescence.

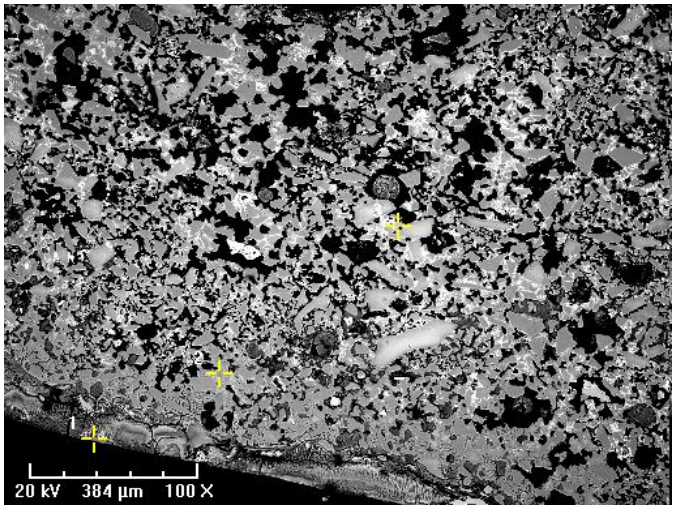


Figure F.230: Profile 2 of New Kingdom bead 2377-4, efflorescence.

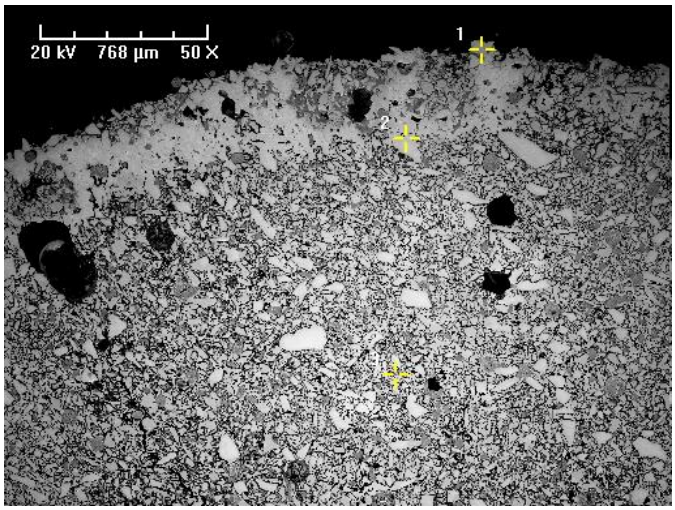


Figure F.231: Profile 1 of New Kingdom bead 2377-5, cementation.

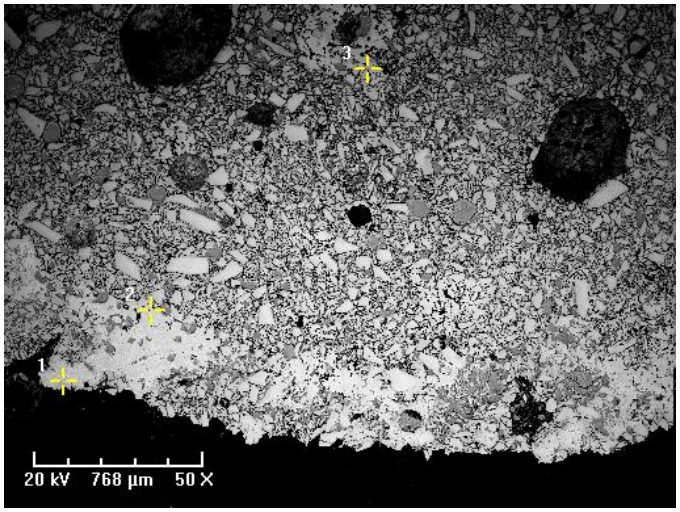


Figure F.232: Profile 2 of New Kingdom bead 2377-5, cementation

Manchester Museum

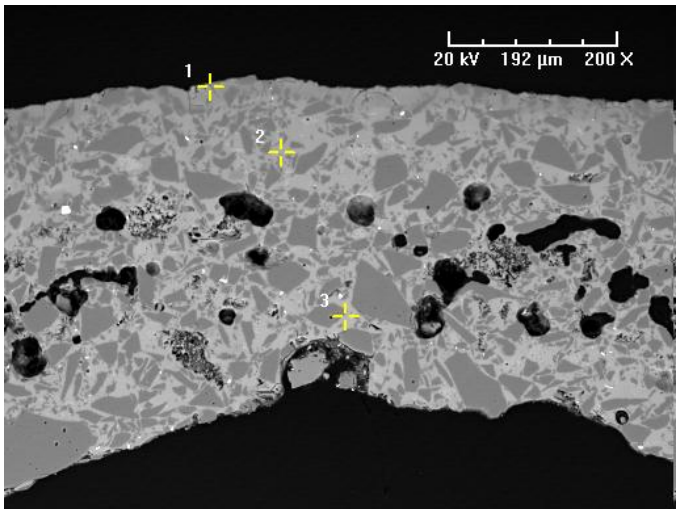


Figure F.233: Profile 1 of New Kingdom bead MAN 4075-1, efflorescence.

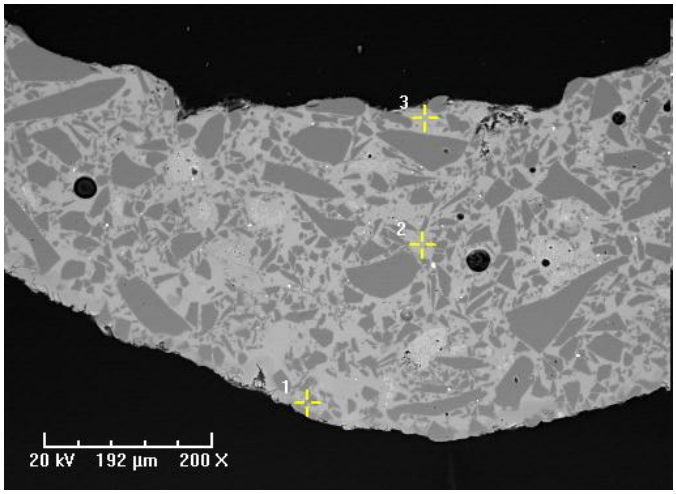


Figure F.234: Profile 2 of New Kingdom bead MAN 4075-1, efflorescence.

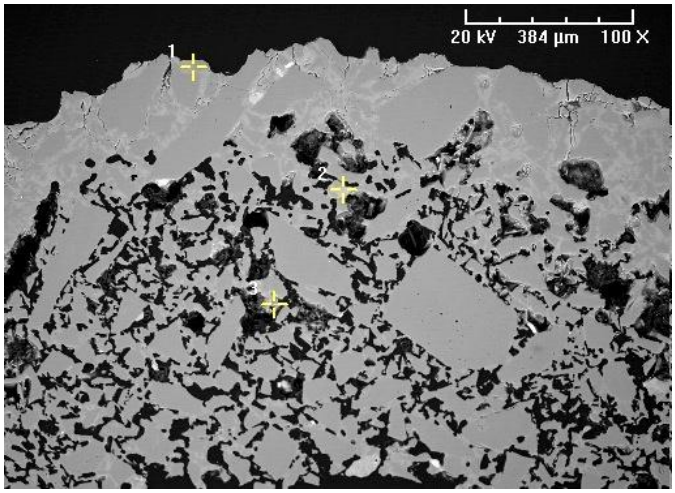


Figure F.235: Profile 1 of New Kingdom bead MAN 4075-2, efflorescence.

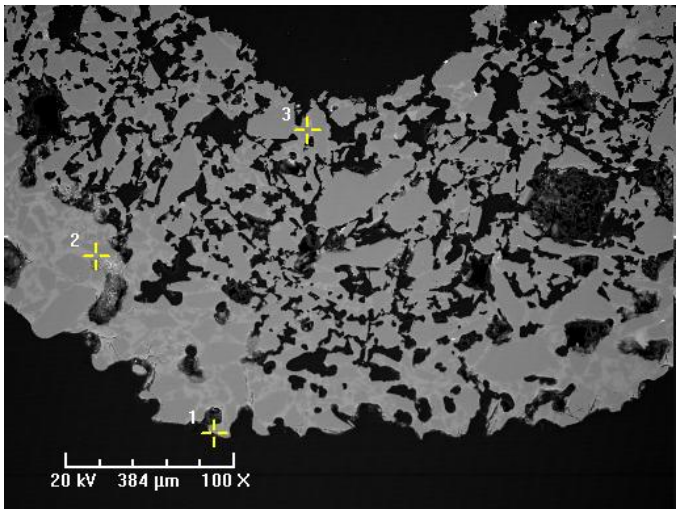


Figure F.236: Profile 2 of New Kingdom bead MAN 4075-2, efflorescence.

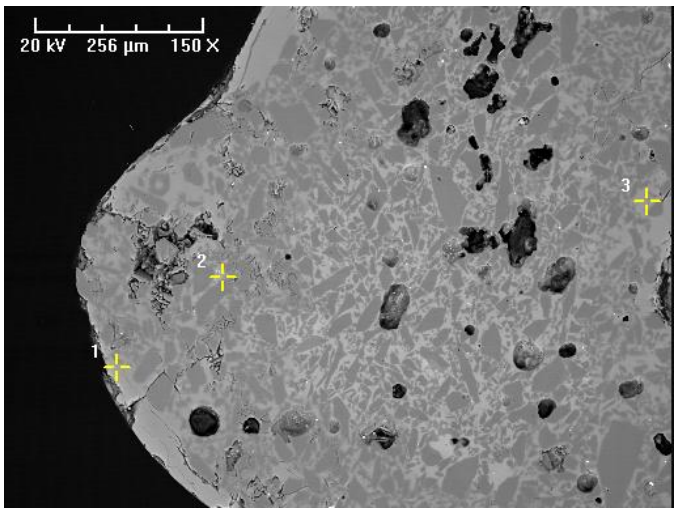


Figure F.237: Profile 1 of New Kingdom bead MAN 4075-3, efflorescence.

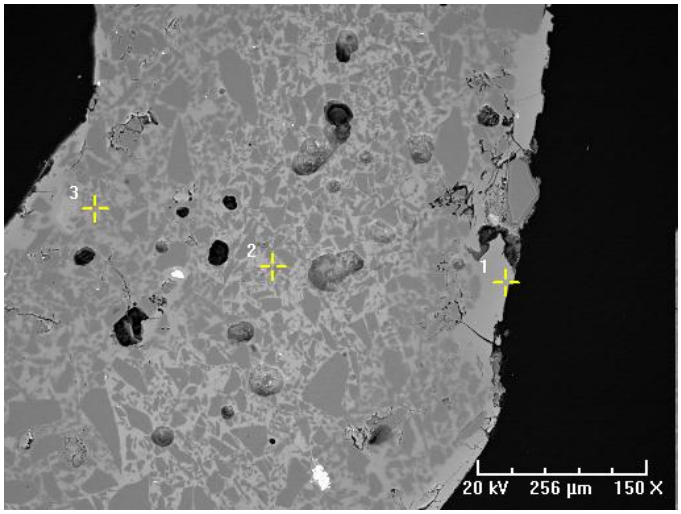


Figure F.238: Profile 2 of New Kingdom bead MAN 4075-3, efflorescence.

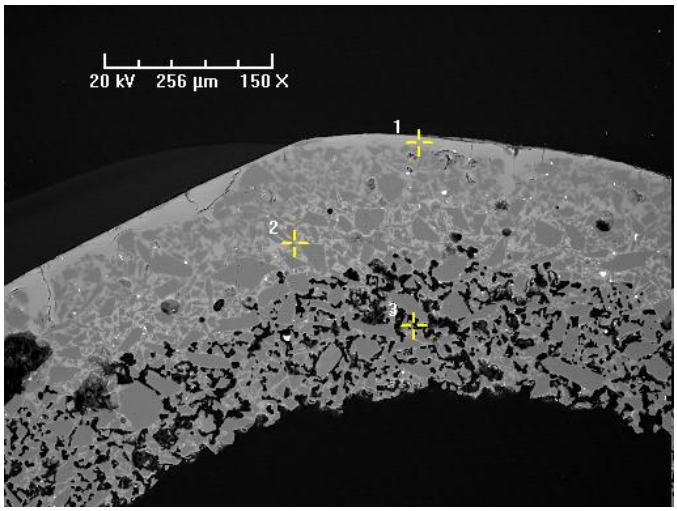


Figure F.239: Profile 1 of New Kingdom bead MAN 4075-4, efflorescence.

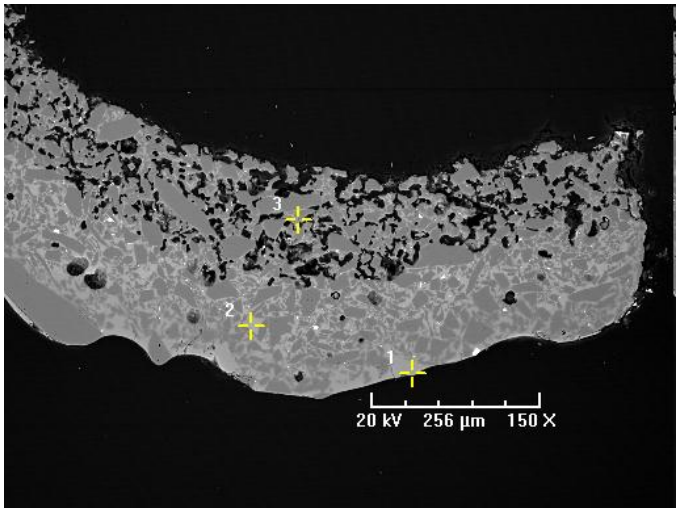


Figure F.240: Profile 2 of New Kingdom bead MAN 4075-4, efflorescence.

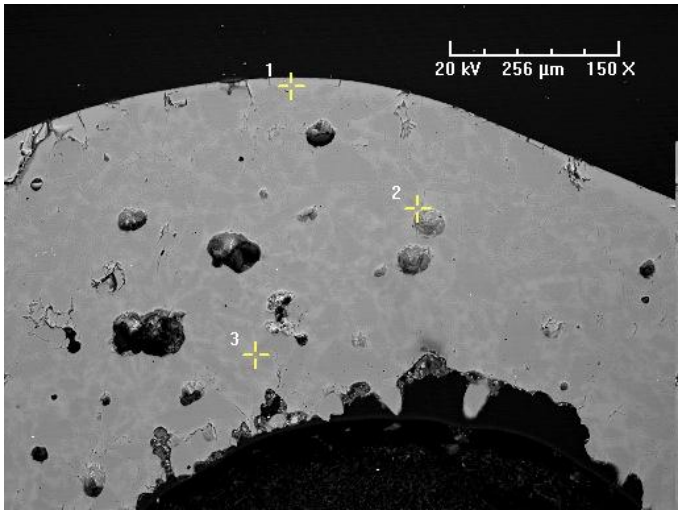


Figure F.241: Profile 1 of New Kingdom bead MAN 4075-5, efflorescence.

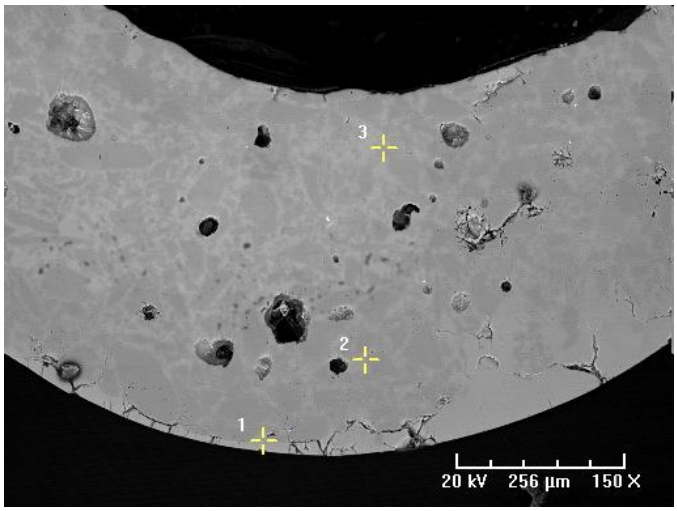


Figure F.242: Profile 2 of New Kingdom bead MAN 4075-5, efflorescence.

Bolton Museum

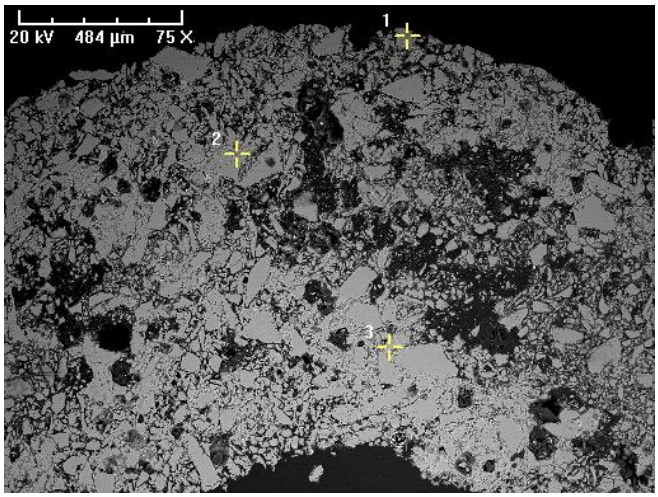


Figure F.243: Profile 1 of Middle Kingdom bead 54.00.75-1, unknown.

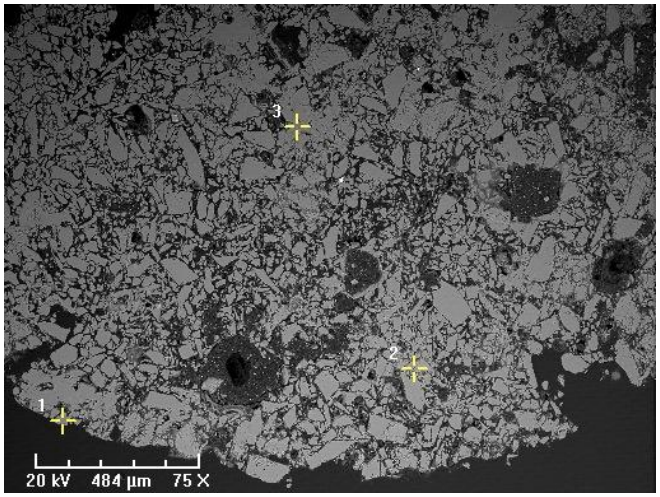


Figure F.244: Profile 2 of Middle Kingdom bead 54.00.75-1, unknown.

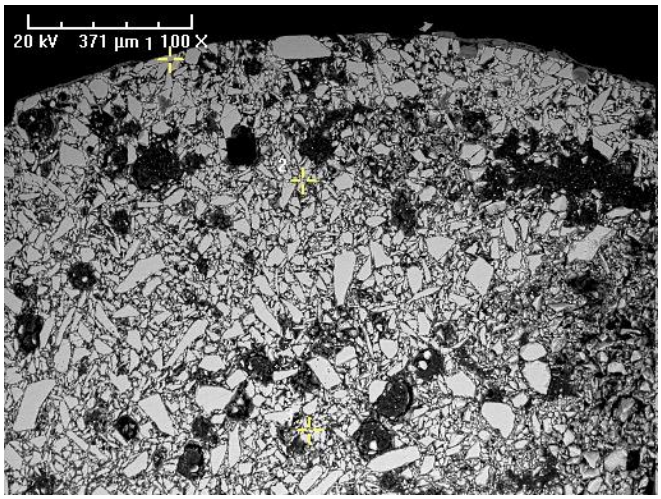


Figure F.245: Profile 1 of Middle Kingdom bead 54.00.75-2, unknown.

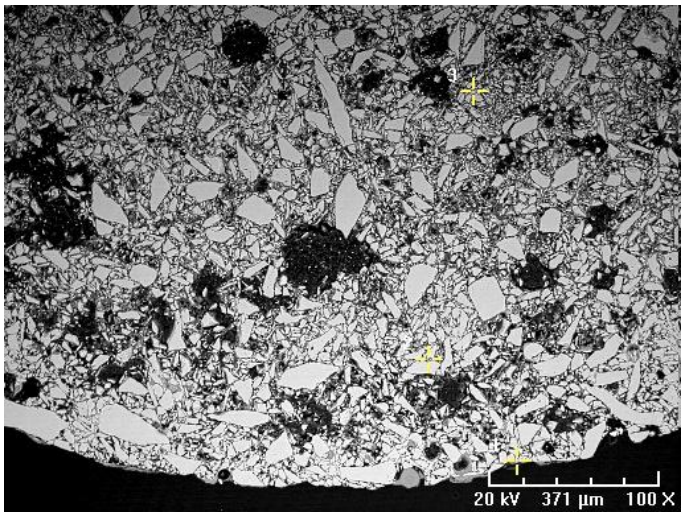


Figure F.246: Profile 2 of Middle Kingdom bead 54.00.75-2, unknown.

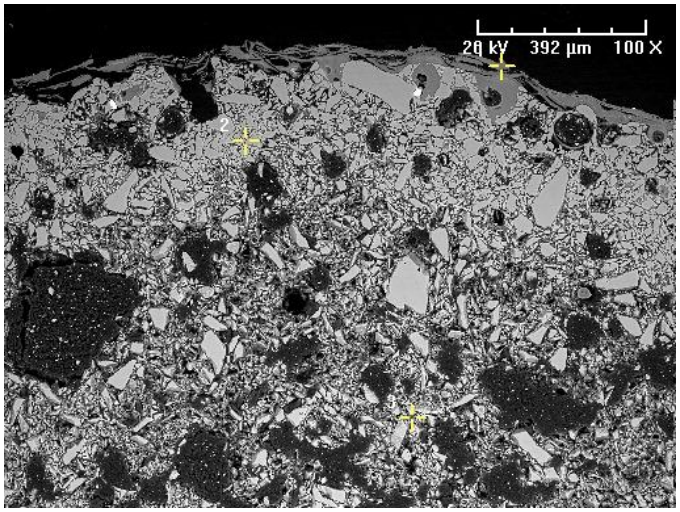


Figure F.247: Profile 1 of Middle Kingdom bead 54.00.75-3, cementation.

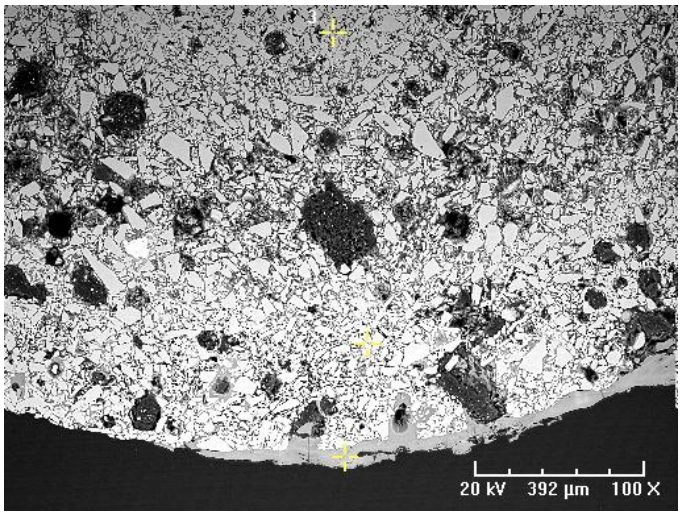


Figure F.248: Profile 2 of Middle Kingdom bead 54.00.75-3, cementation.

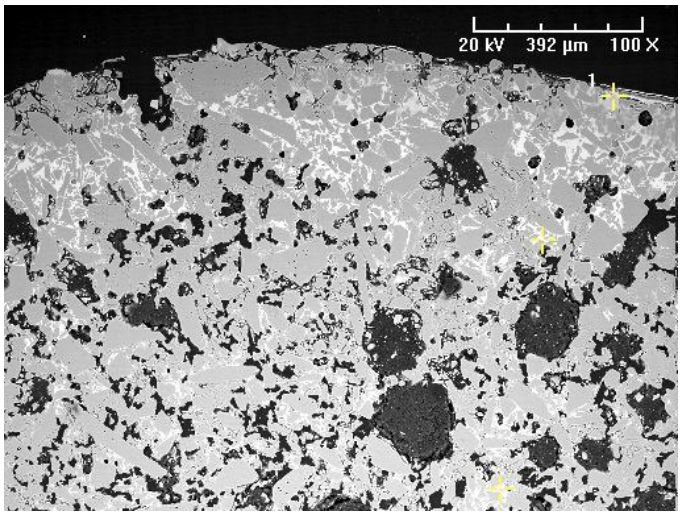


Figure F.249: Profile 1 of Middle Kingdom bead 54.00.75-4, efflorescence.

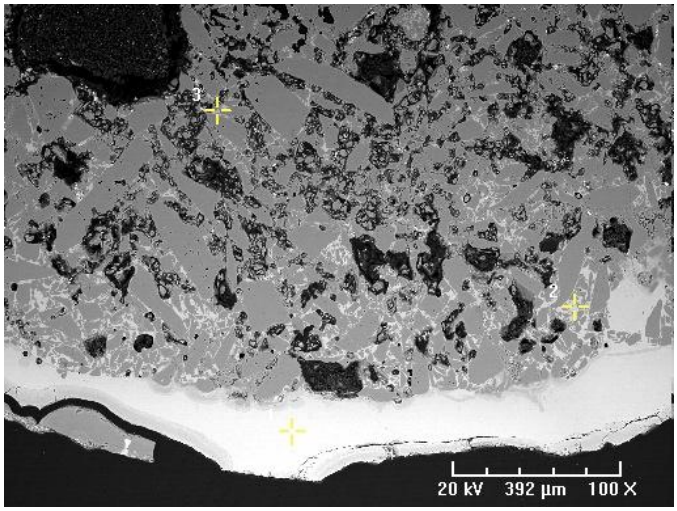


Figure F.250: Profile 2 of Middle Kingdom bead 54.00.75-4, efflorescence.

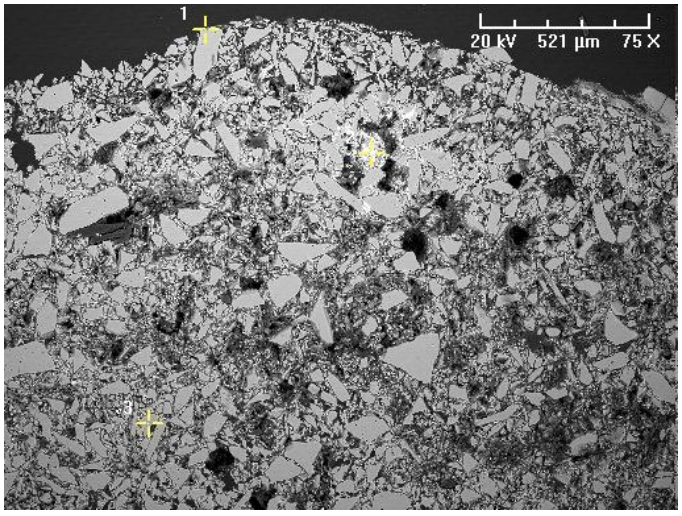


Figure F.251: Profile 1 of Middle Kingdom bead 54.00.75-5, unknown.

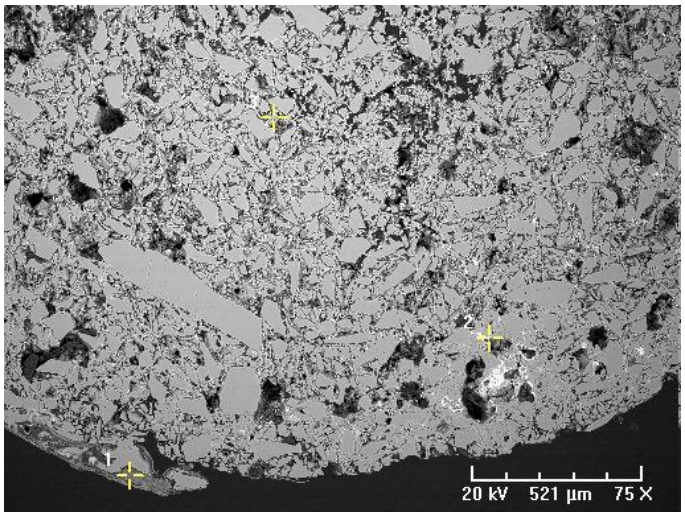


Figure F.252: Profile 2 of Middle Kingdom bead 54.00.75-5, unknown.

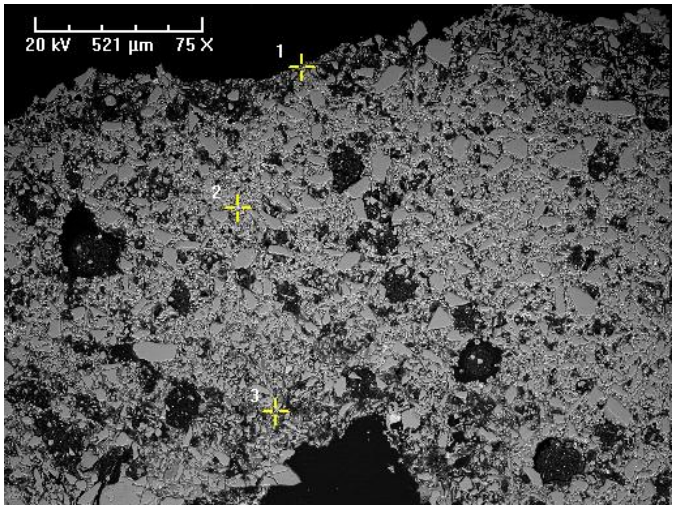


Figure F.253: Profile 1 of Middle Kingdom bead 54.00.75-6, unknown.

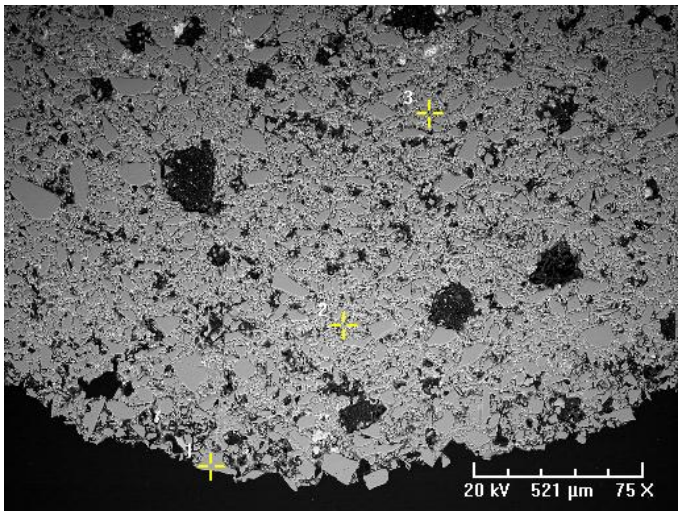


Figure F.254: Profile 2 of Middle Kingdom bead 54.00.75-6, unknown.

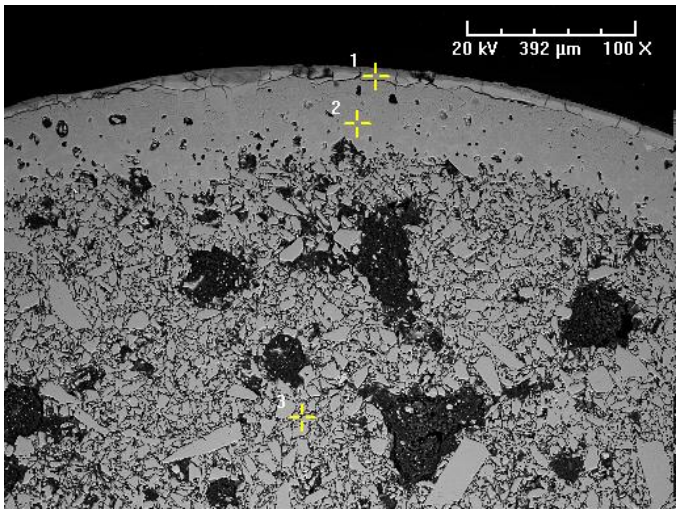


Figure F.255: Profile 1 of Middle Kingdom bead 54.00.75-7, cementation.

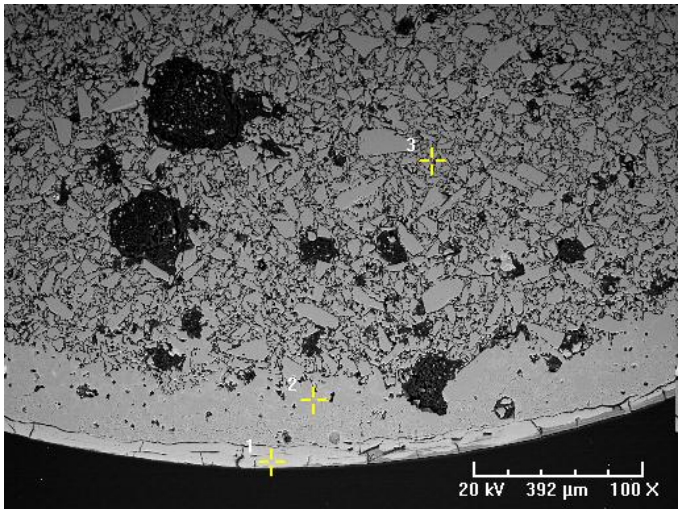


Figure F.256: Profile 2 of Middle Kingdom bead 54.00.75-7, cementation.

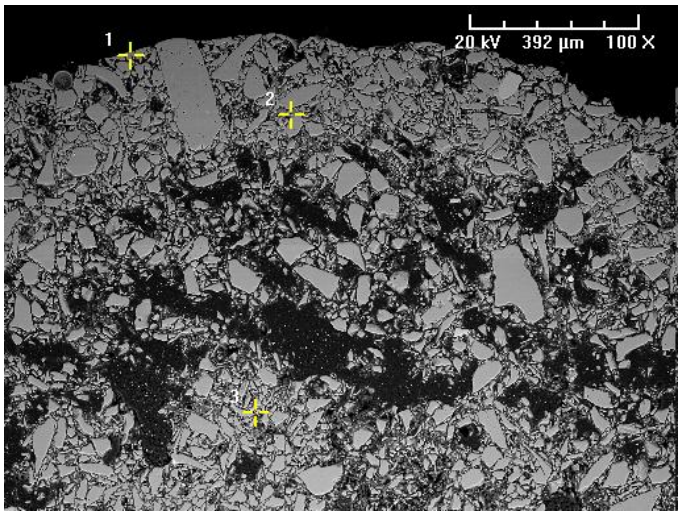


Figure F.257: Profile 1 of Middle Kingdom bead 54.00.75-8, unkown.

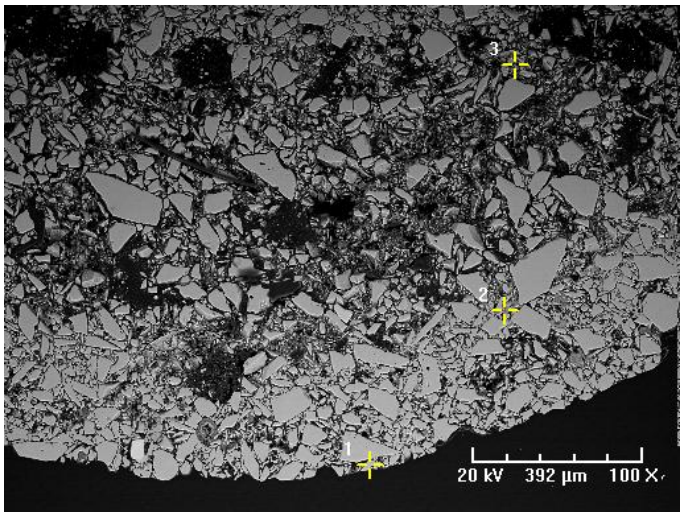


Figure F.258: Profile 2 of Middle Kingdom bead 54.00.75-8, unknown.

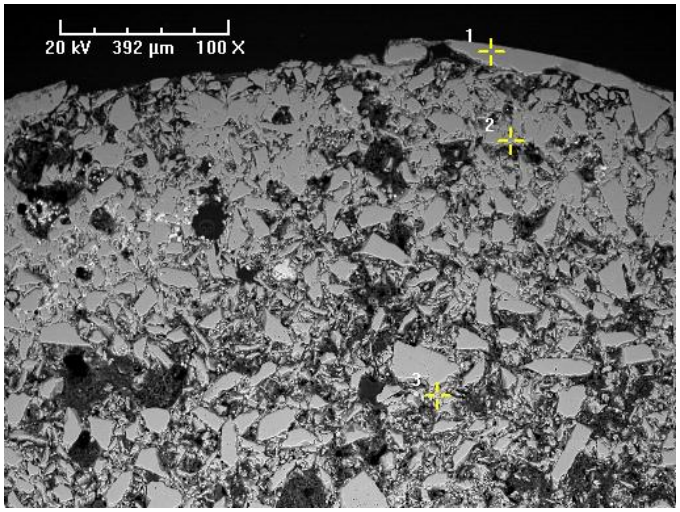


Figure F.259: Profile 1 of Middle Kingdom bead 54.00.75-9, unknown.

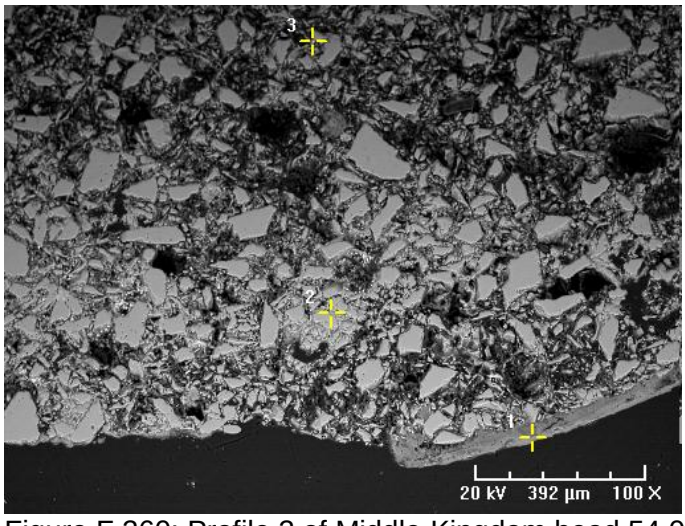


Figure F.260: Profile 2 of Middle Kingdom bead 54.00.75-9, unknown.

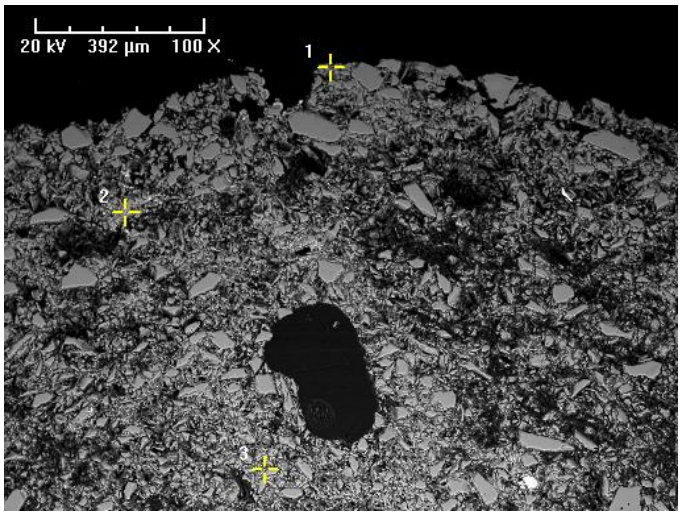


Figure F.261: Profile 1 of Middle Kingdom bead 54.00.75-10, unknown.

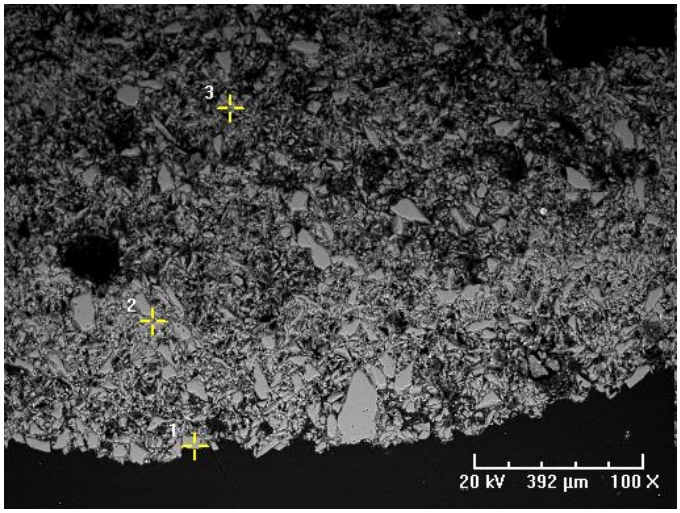


Figure F.262: Profile 2 of Middle Kingdom bead 54.00.75-10, unknown.

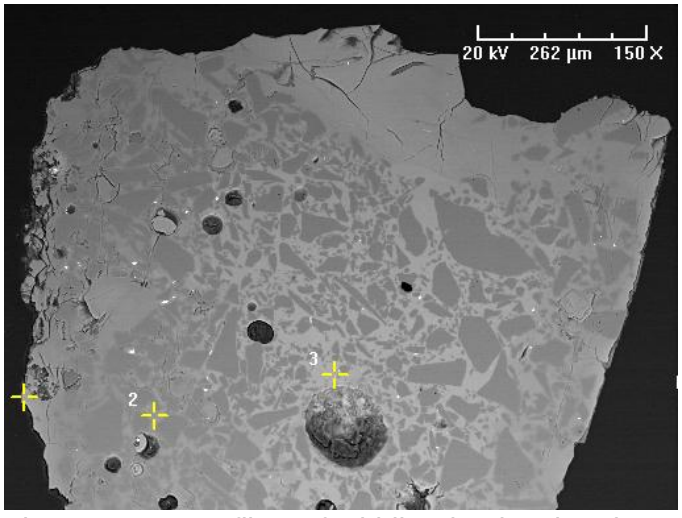


Figure F.263: Profile 1 of Middle Kingdom bead 54.00.79-1, efflorescence.

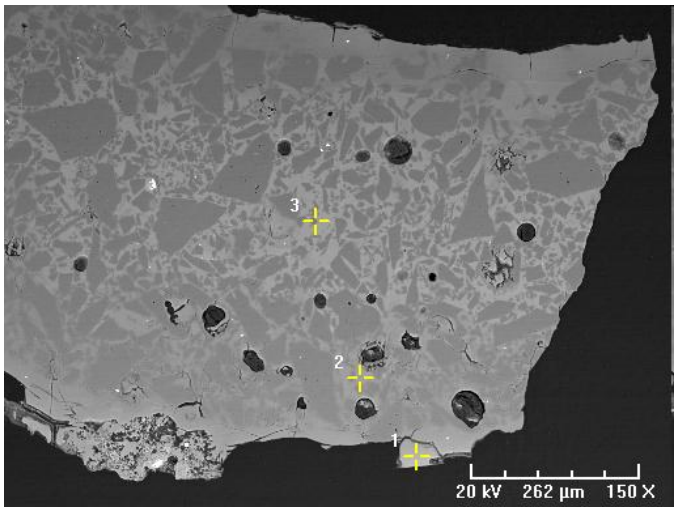


Figure F. 264: Profile 2 of Middle Kingdom bead 54.00.79-1, efflorescence.

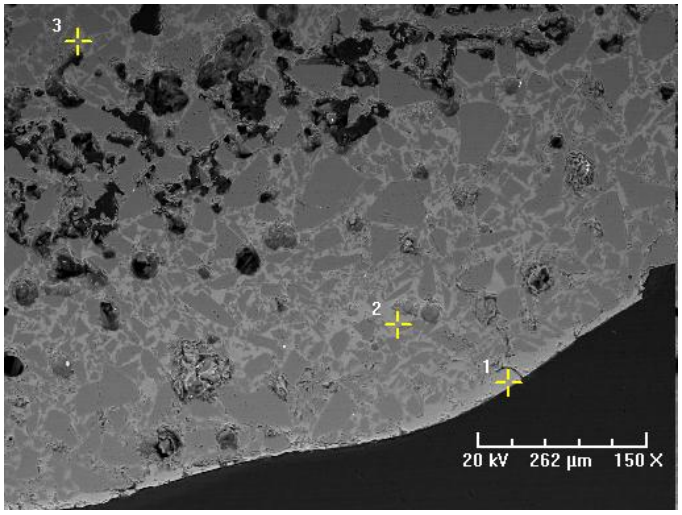


Figure F. 265: Profile 1 of Middle Kingdom bead 54.00.79-2, efflorescence.

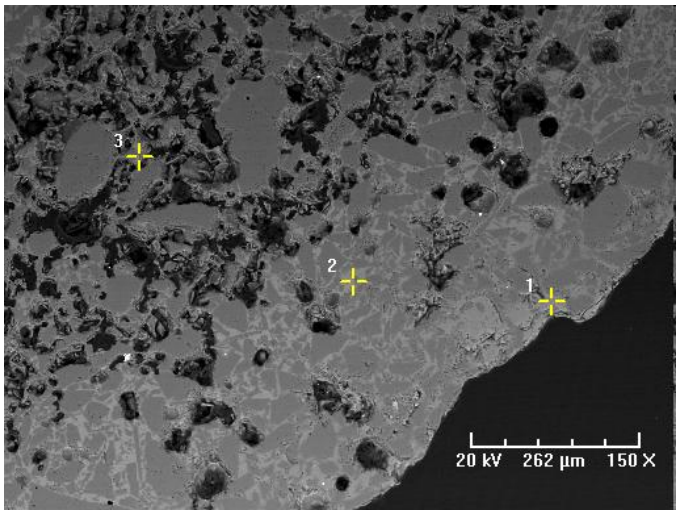


Figure F. 266: Profile 2 of Middle Kingdom bead 54.00.79-2, efflorescence.

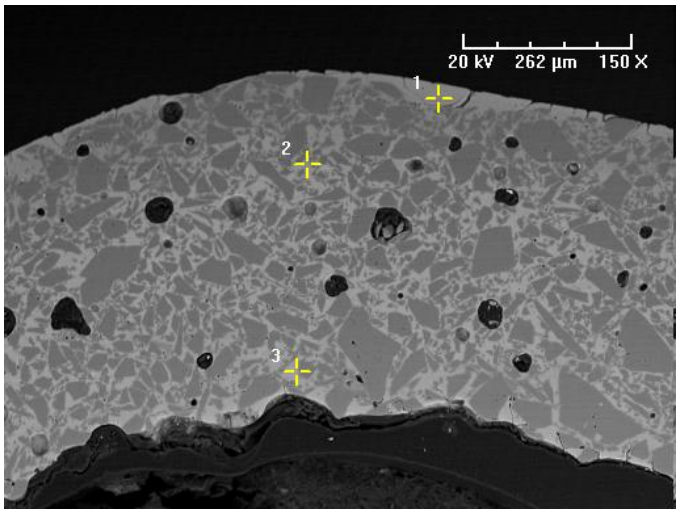


Figure F. 267: Profile 1 of Middle Kingdom bead 54.00.79-3, efflorescence.

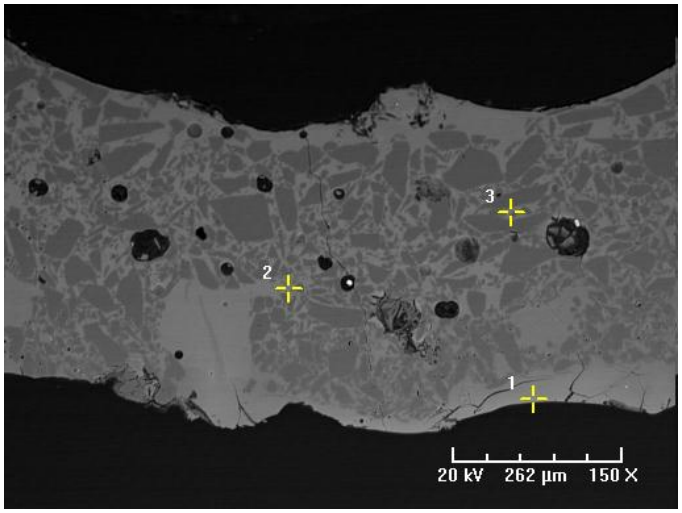


Figure F. 268: Profile 2 of Middle Kingdom bead 54.00.79-3, efflorescence.

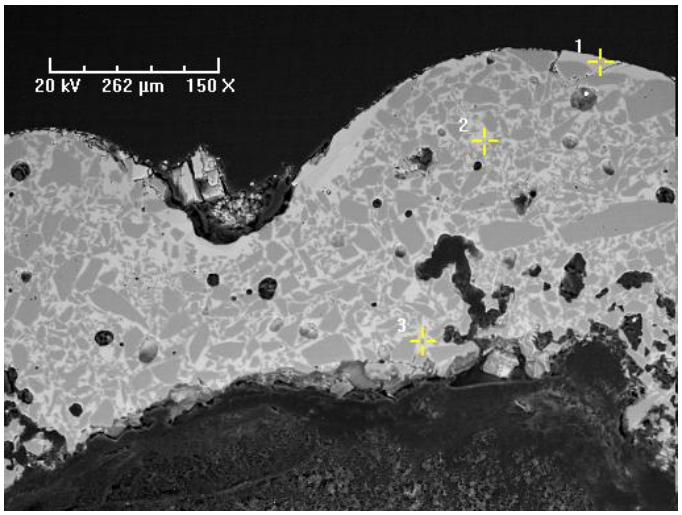


Figure F. 269: Profile 1 of Middle Kingdom bead 54.00.79-4, efflorescence.

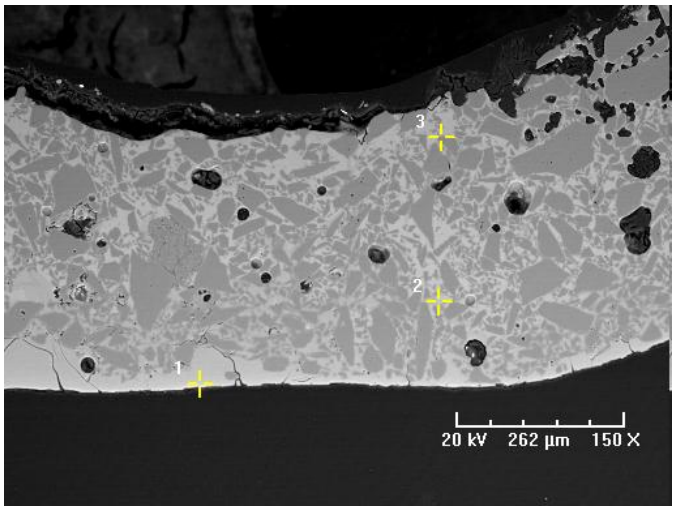


Figure F. 270: Profile 2 of Middle Kingdom bead 54.00.79-4, efflorescence.

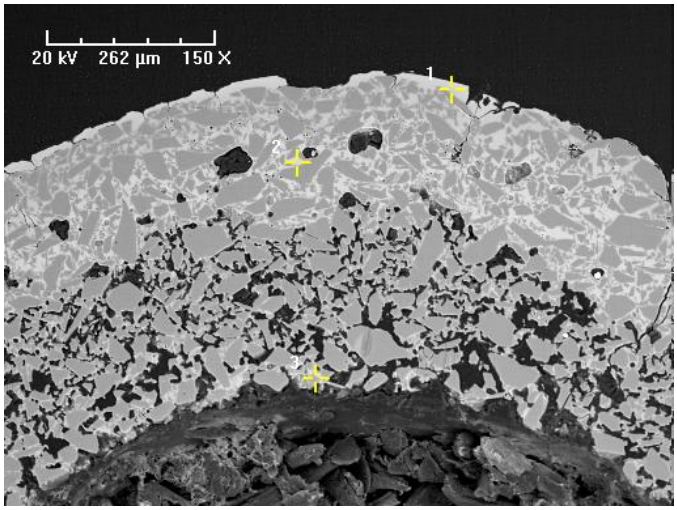


Figure F. 271: Profile 1 of Middle Kingdom bead 54.00.79-5, efflorescence.

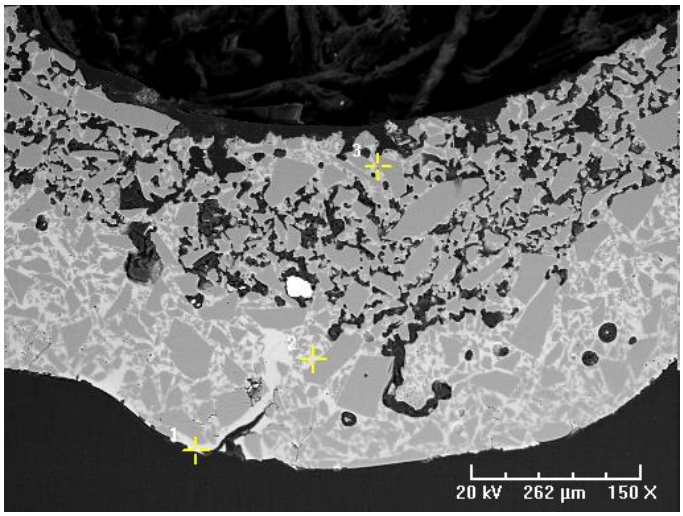


Figure F. 272: Profile 2 of Middle Kingdom bead 54.00.79-5, efflorescence.

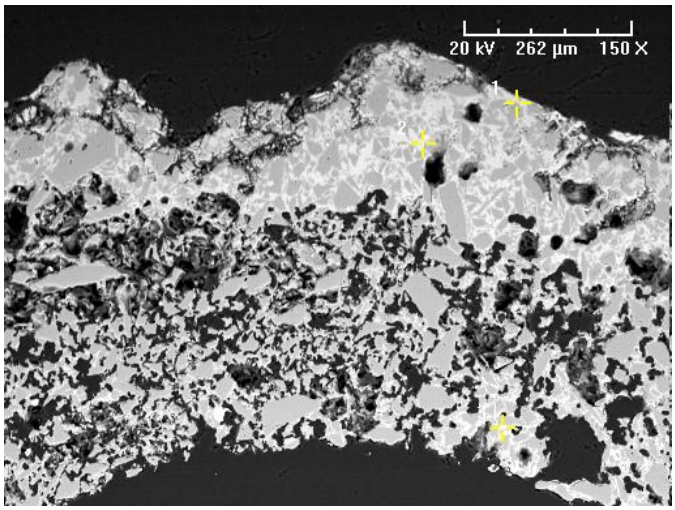


Figure F. 273: Profile 1 of Middle Kingdom bead 54.00.79-6, efflorescence.

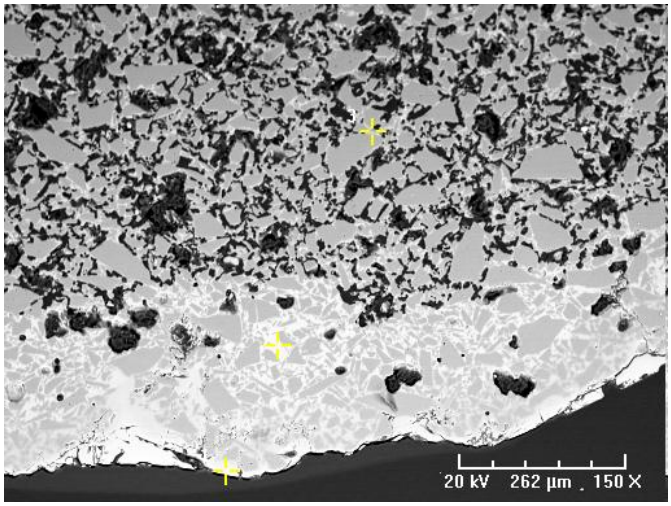


Figure F. 274: Profile 2 of Middle Kingdom bead 54.00.79-6, efflorescence.

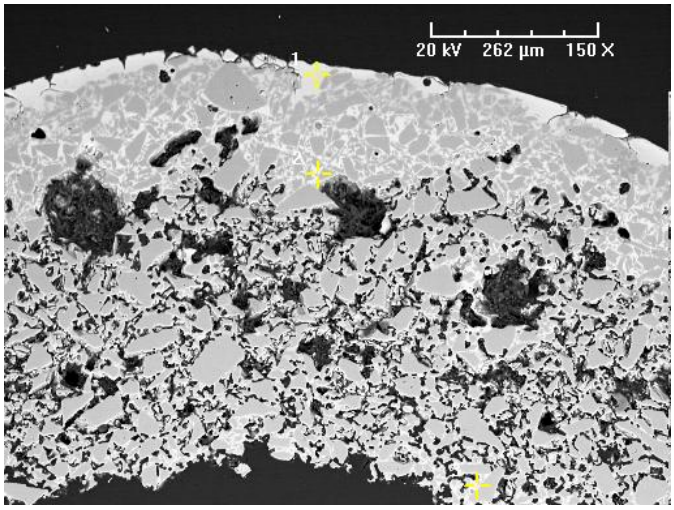


Figure F. 275: Profile 1 of Middle Kingdom bead 54.00.79-7, efflorescence.

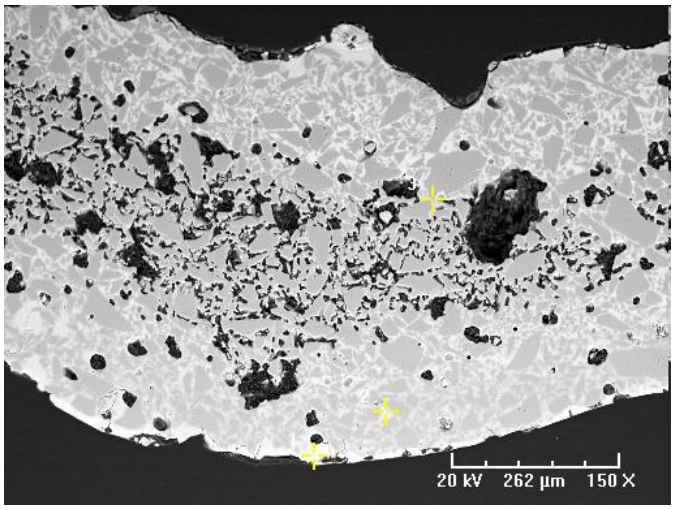


Figure F. 276: Profile 2 of Middle Kingdom bead 54.00.79-7, efflorescence.

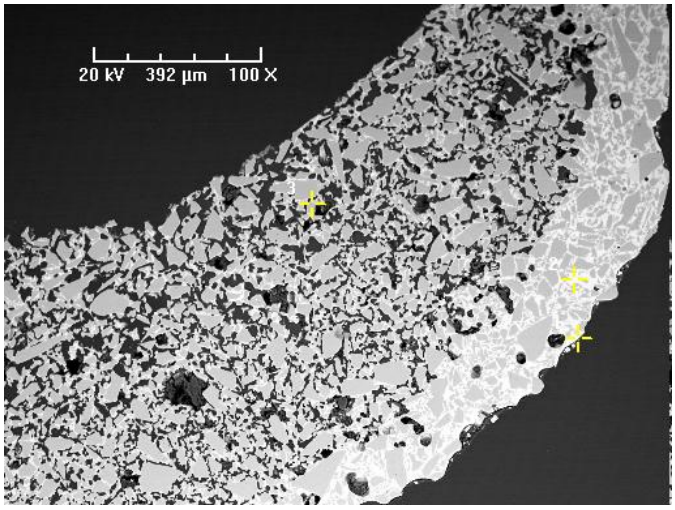


Figure F. 277: Profile 1 of Middle Kingdom bead 54.00.79-8, efflorescence.

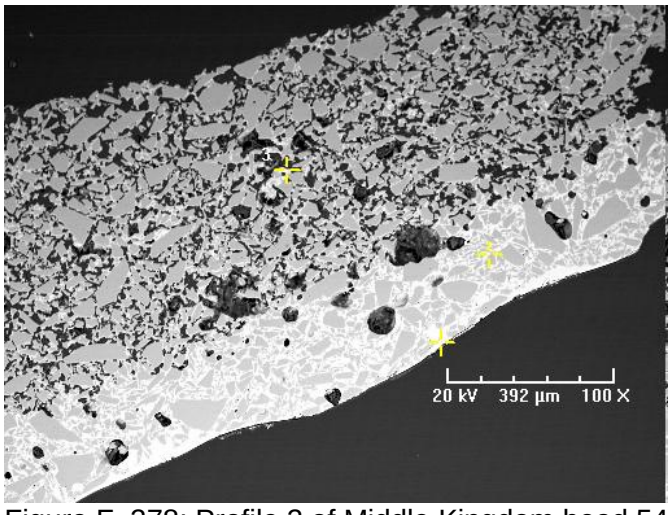


Figure F. 278: Profile 2 of Middle Kingdom bead 54.00.79-8, efflorescence.

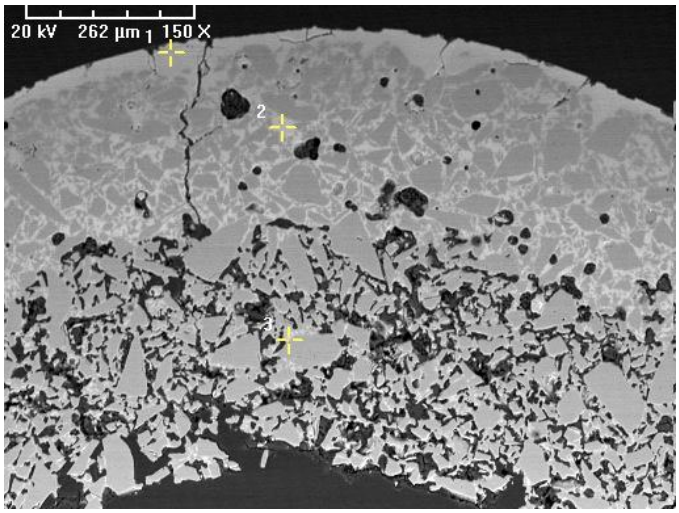


Figure F. 279: Profile 1 of Middle Kingdom bead 54.00.79-9, efflorescence.

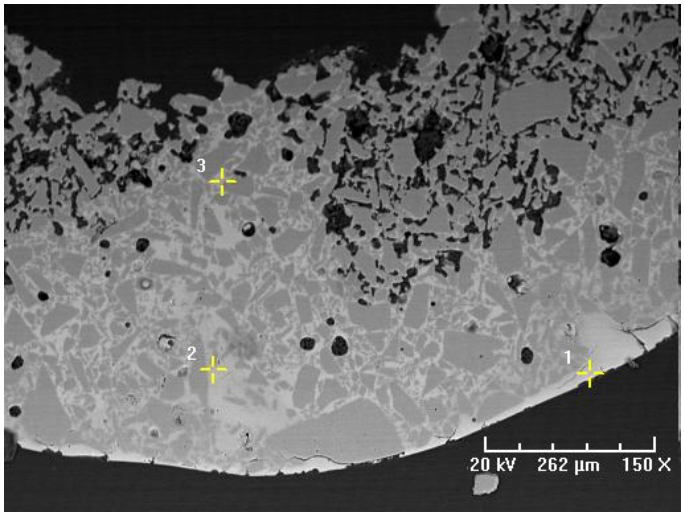


Figure F. 280: Profile 2 of Middle Kingdom bead 54.00.79-9, efflorescence.

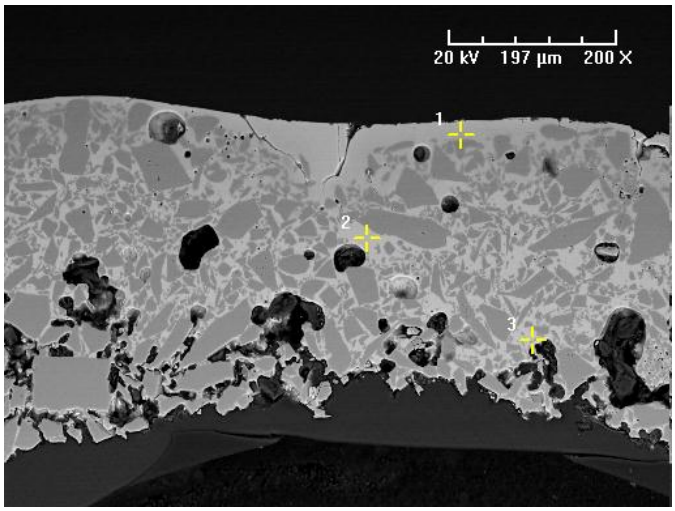


Figure F. 281: Profile 1 of Middle Kingdom bead 54.00.79-10, efflorescence.

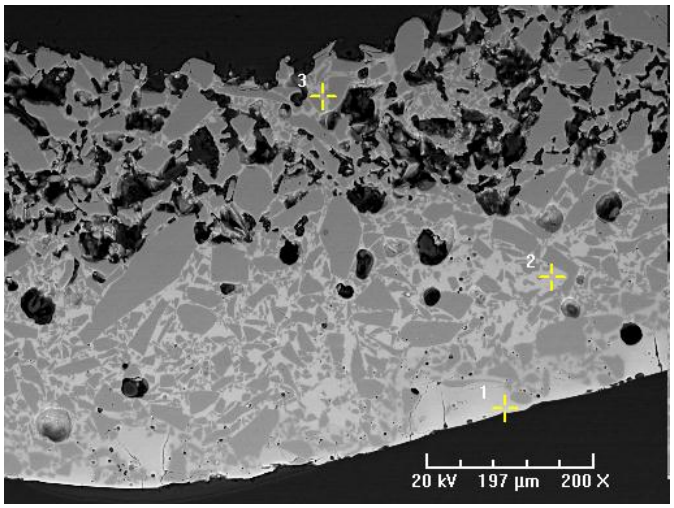


Figure F. 282: Profile 2 of Middle Kingdom bead 54.00.79-10, efflorescence.

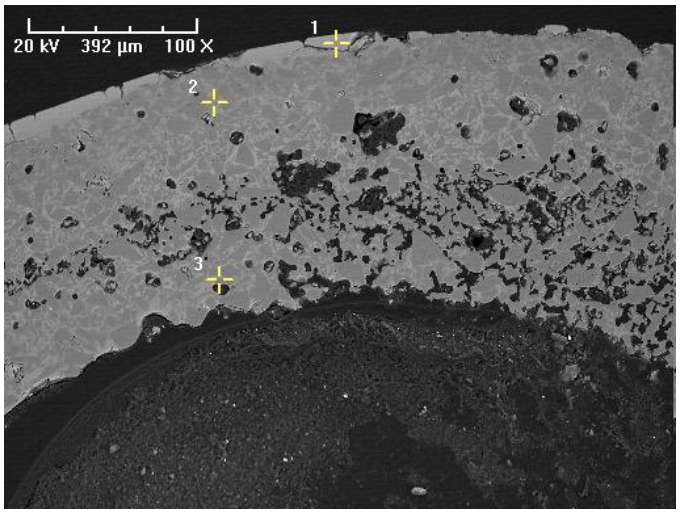


Figure F. 283: Profile 1 of Middle Kingdom bead 54.00.79?-1, efflorescence.

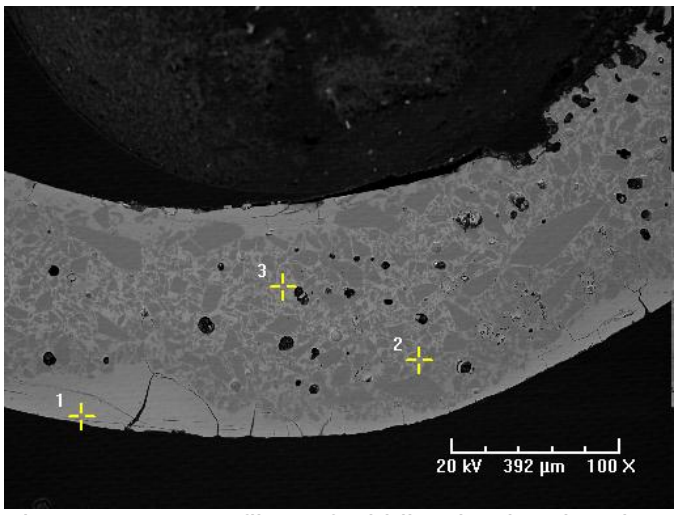


Figure F. 284: Profile 2 of Middle Kingdom bead 54.00.79?-1, efflorescence.

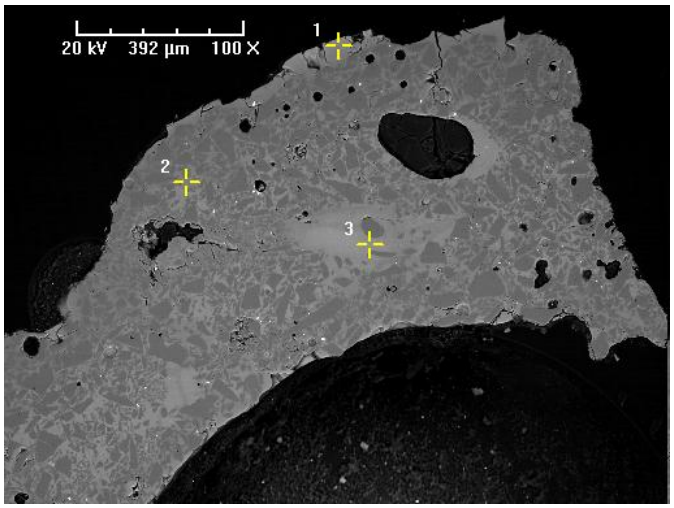


Figure F. 285: Profile 1 of Middle Kingdom bead 54.00.79?-2, efflorescence.

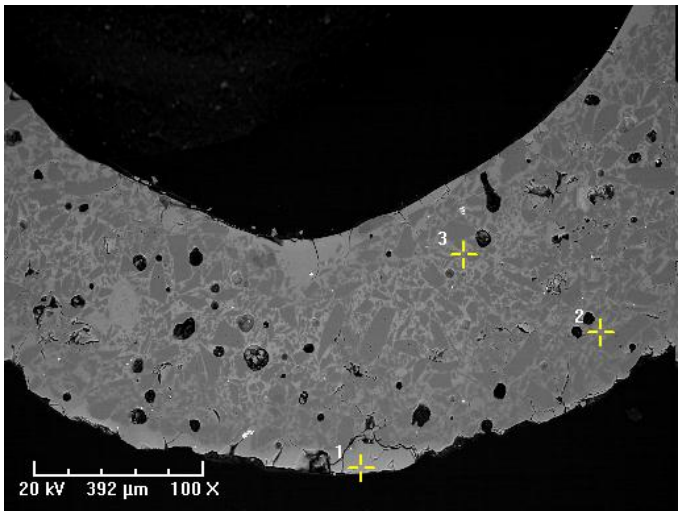


Figure F. 286: Profile 2 of Middle Kingdom bead 54.00.79?-2, efflorescence.

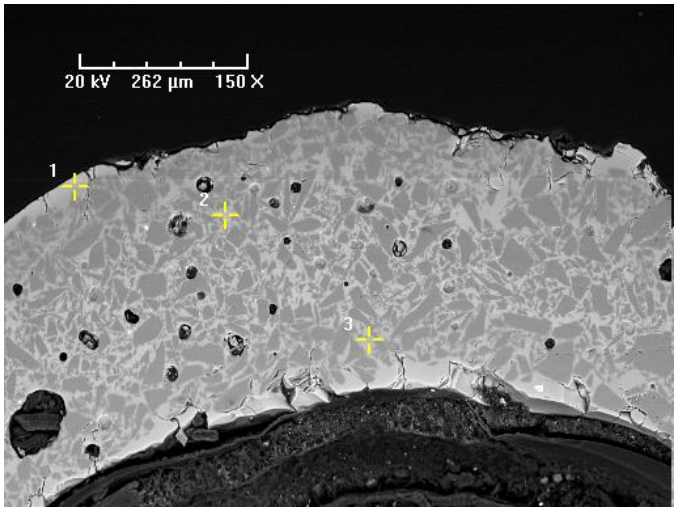


Figure F. 287: Profile 1 of Middle Kingdom bead 54.00.79?-3, efflorescence.

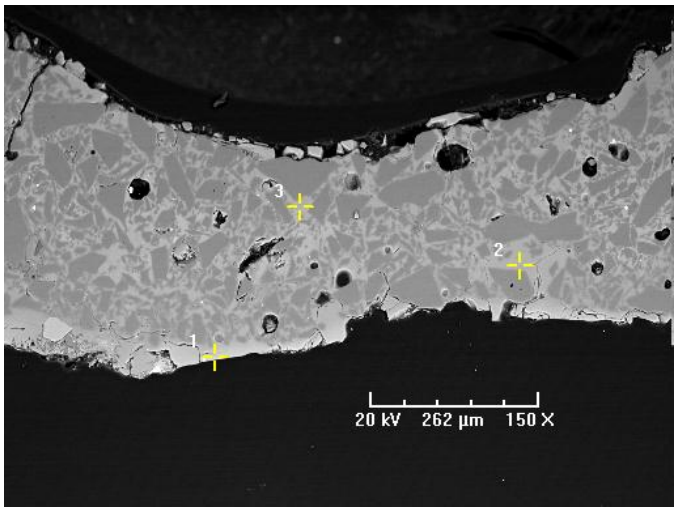


Figure F. 288: Profile 2 of Middle Kingdom bead 54.00.79?-3, efflorescence.

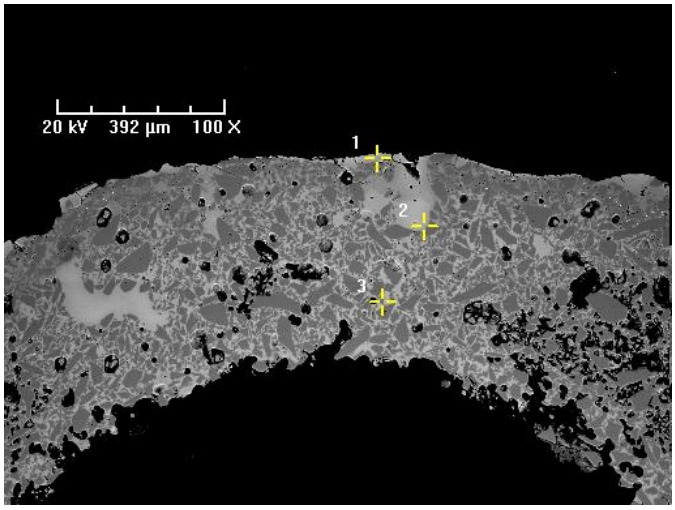


Figure F. 289: Profile 1 of Middle Kingdom bead 54.00.79?-4, efflorescence.

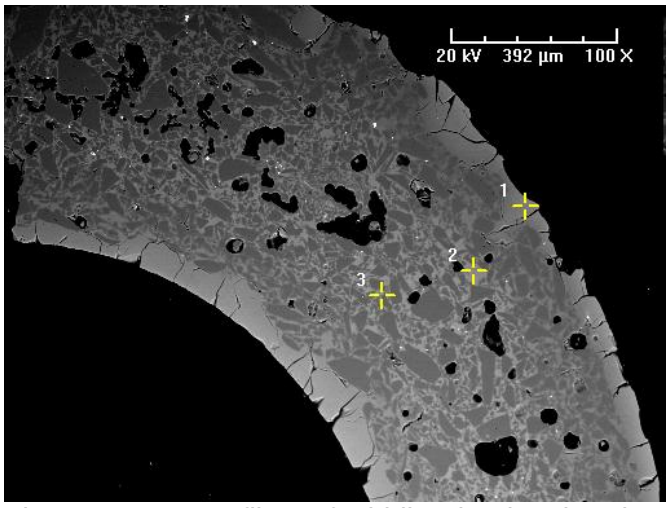


Figure F. 290: Profile 2 of Middle Kingdom bead 54.00.79?-4, efflorescence.

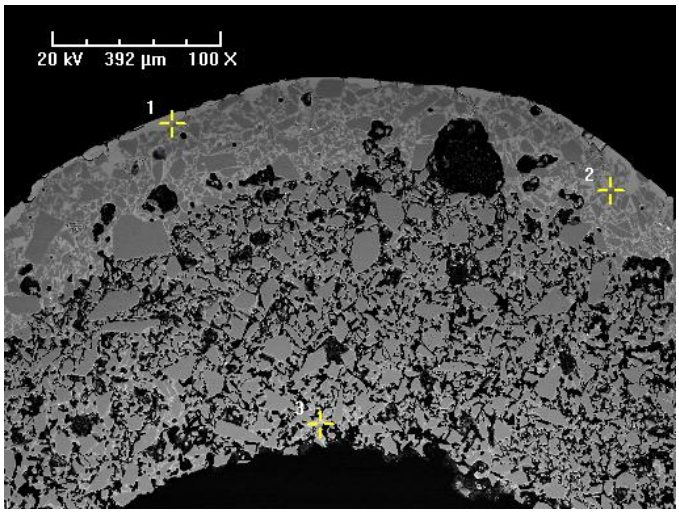


Figure F. 291: Profile 1 of Middle Kingdom bead 54.00.79?-5, cementation.

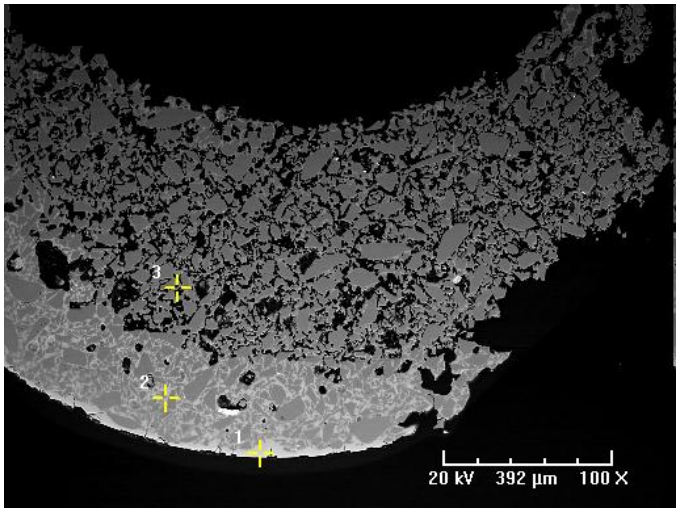


Figure F. 292: Profile 2 of Middle Kingdom bead 54.00.79?-5, cementation.

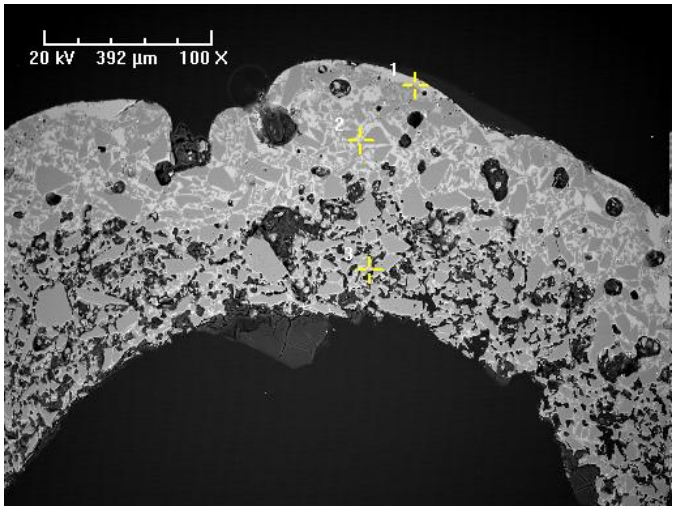


Figure F. 293: Profile 1 of Middle Kingdom bead 54.00.79?-6, efflorescence.

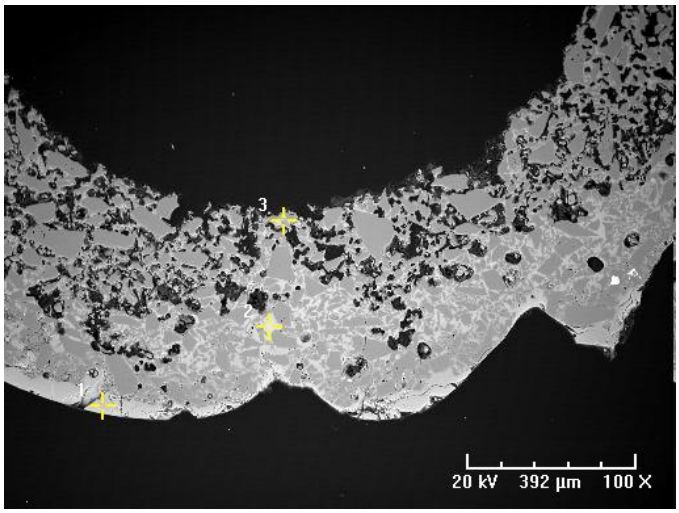


Figure F. 294: Profile 2 of Middle Kingdom bead 54.00.79?-6, efflorescence.

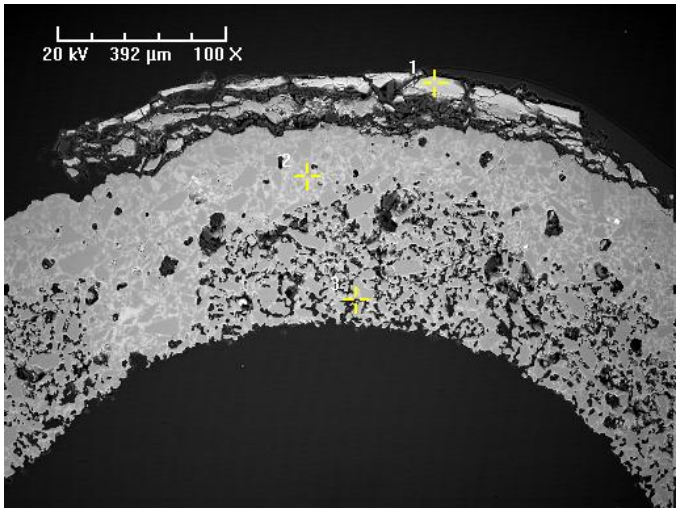


Figure F. 295: Profile 1 of Middle Kingdom bead 54.00.79?-7, efflorescence.

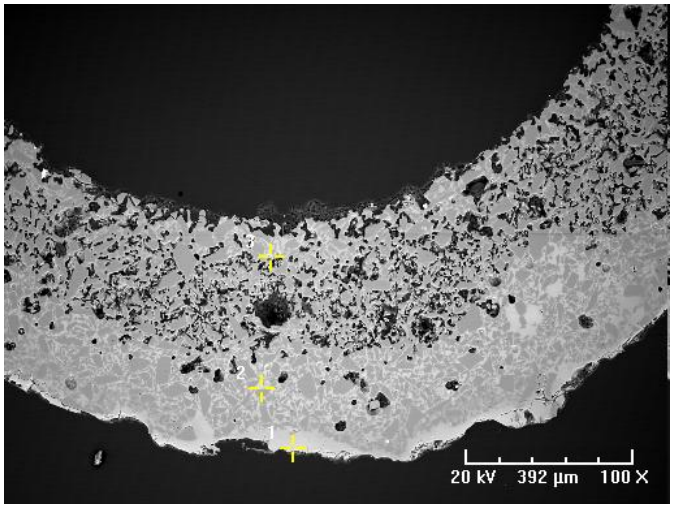


Figure F. 296: Profile 2 of Middle Kingdom bead 54.00.79?-7, efflorescence.

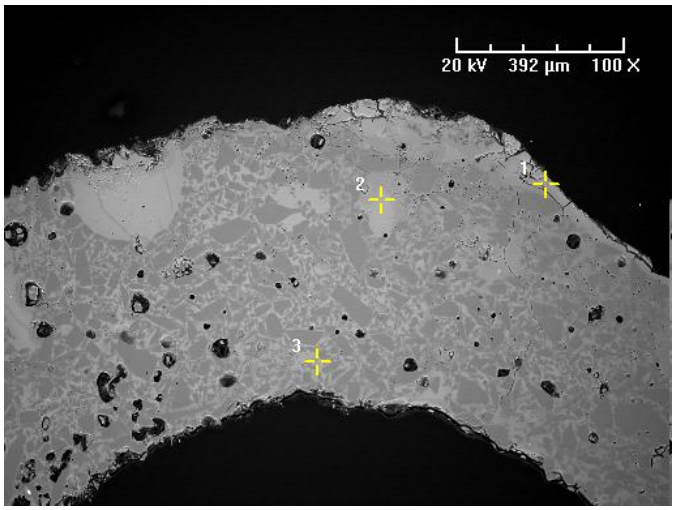


Figure F. 297: Profile 1 of Middle Kingdom bead 54.00.79?-8, efflorescence.

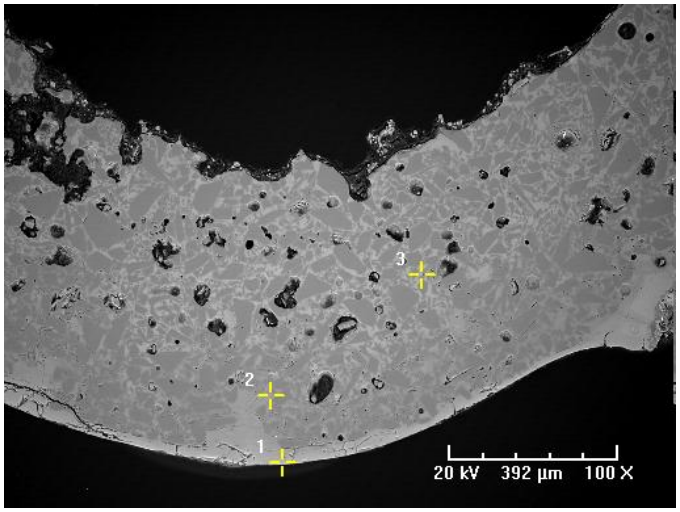


Figure F. 298: Profile 2 of Middle Kingdom bead 54.00.79?-8, efflorescence.

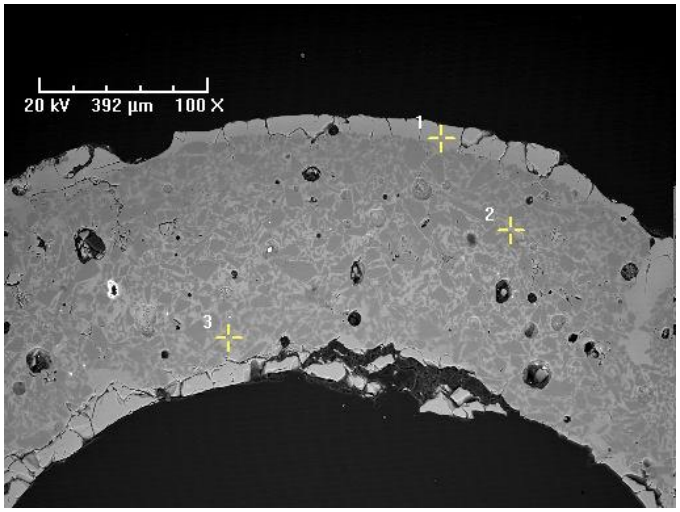


Figure F. 299: Profile 1 of Middle Kingdom bead 54.00.79?-9, efflorescence.

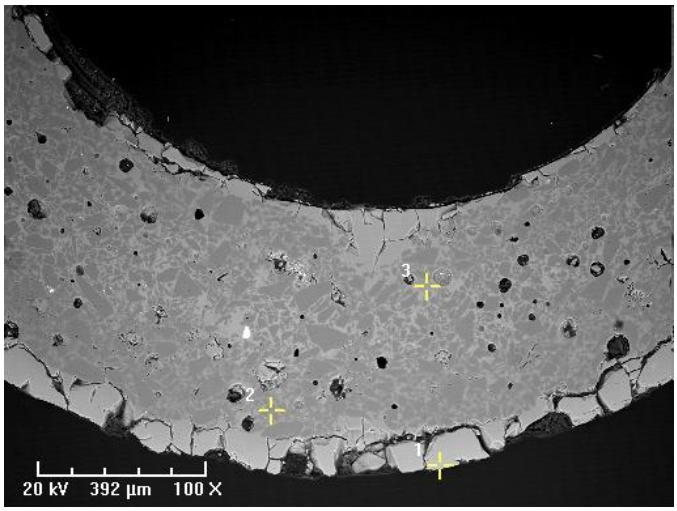


Figure F. 300: Profile 2 of Middle Kingdom bead 54.00.79?-9, efflorescence.

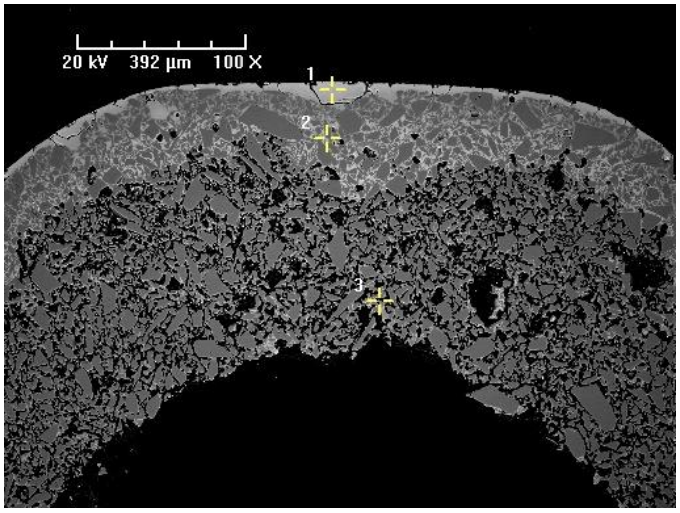


Figure F. 301: Profile 1 of Middle Kingdom bead 54.00.79?-10, cementation.

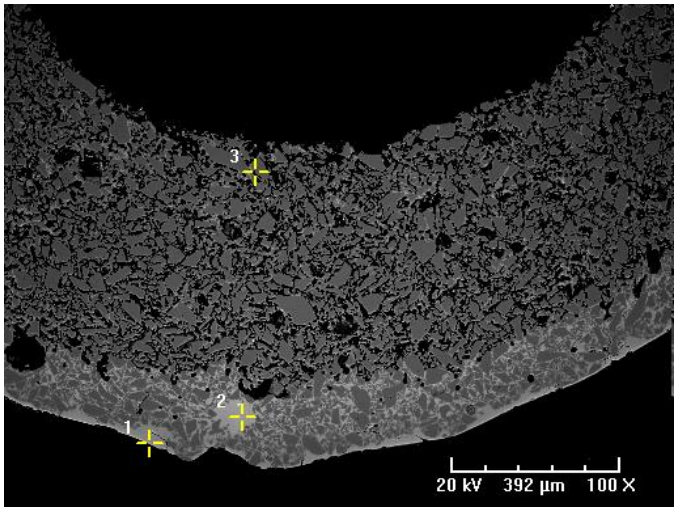


Figure F. 302: Profile 2 of Middle Kingdom bead 54.00.79?-10, cementation.

Appendix G: EDS Analysis Raw Data

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2130-1	Core 1	93.95	0.42	1.00	0.03	<0.83	<0.42	<0.65	<0.47	3.77	<0.69							
MK	2130-1	Core 1 Re.	95.10	0.88	<0.40	0.29	0.07	0.25	<0.65	<0.47	1.00	<0.69							
MK	2130-1	Core 2	85.97	<0.29	1.35	0.54	0.35	<0.42	<0.65	<0.47	14.89	0.56							
MK	2130-1	Core 2 Re.	87.70	0.75	0.90	0.19	0.09	0.30	<0.65	<0.47	8.20	<0.69		0.43					
MK	2130-1	Glaze 1	72.28	<0.29	1.88	0.79	0.37	0.48	2.83	<0.47	22.01	0.08							
MK	2130-1	Glaze 1 Re.	88.15	0.80	0.95	0.09	0.12	0.26	<0.65	<0.47	12.35	<0.69							
MK	2130-1	Glaze 2	89.28	<0.29	0.79	0.24	1.08	<0.42	<0.65	<0.47	12.05	<0.69							
MK	2130-1	Glaze 2 Re.	79.17	0.91	5.44	0.39	0.08	0.17	<0.65	<0.47	10.22	<0.69		0.96		2.66			
MK	2130-1	Interparticle 1	88.99	0.29	0.94	1.03	<0.83	<0.42	<0.65	<0.47	11.69	<0.69							
MK	2130-1	Interparticle 1 Re.	84.03	1.05	1.60	0.38	0.16	<0.42	<0.65	<0.47	12.94	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2130-1	Interparticle 2	87.21	0.59	1.23	0.07	0.17	0.09	1.44	<0.47	10.79	<0.69							
MK	2130-1	Interparticle 2 Re.	96.45	0.90	0.08	0.30	0.13	0.23	<0.65	<0.47	1.45	<0.69							
MK	2130-2	Core 1	83.54	0.35	0.62	0.01	0.09	0.10	1.84	<0.47	11.09	<0.69		1.70					
MK	2130-2	Core 1 Re.	97.25	0.94	<0.40	0.35	0.07	0.31	<0.65	<0.47	0.82	<0.69		0.16					
MK	2130-2	Core 2	91.75	0.61	0.39	<0.63	0.19	<0.42	1.32	<0.47	4.27	<0.69							
MK	2130-2	Core 2 Re.	92.06	0.61	0.34	<0.63	0.06	0.35	0.93	<0.47	5.75	<0.69		0.55					
MK	2130-2	Glaze 1	85.72	<0.29	1.55	<0.63	0.54	<0.42	<0.65	<0.47	15.19	<0.69							
MK	2130-2	Glaze 1 Re.	75.01	0.53	1.26	0.47	0.14	0.35	3.27	<0.47	18.94	<0.69		0.77					
MK	2130-2	Glaze 2	83.51	0.13	2.44	0.11	0.35	0.01	<0.65	<0.47	12.82	<0.69							
MK	2130-2	Glaze 2 Re.	88.52	0.58	2.15	0.05	<0.83	0.29	0.57	<0.47	7.91	<0.69		0.81					
MK	2130-2	Interparticle 1	92.08	0.38	0.58	0.45	0.22	0.03	<0.65	<0.47	7.55	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2130-2	Interparticle 1 Re.	90.43	0.94	0.38	0.33	0.20	0.29	<0.65	<0.47	8.06	<0.69		0.77					
MK	2130-2	Interparticle 2	85.50	0.29	1.12	1.83	0.16	0.02	<0.65	<0.47	11.97	<0.69							
MK	2130-2	Interparticle 2 Re.	91.55	0.70	0.68	0.21	<0.83	0.08	<0.65	<0.47	3.77	<0.69		0.23					
MK	2130-3	Core 1	89.97	0.19	1.94	<0.63	0.35	0.02	0.26	<0.47	7.72	0.06							
MK	2130-3	Core 1 Re.	96.31	0.88	0.04	0.37	0.17	0.25	0.38	<0.47	1.24	<0.69		0.12					
MK	2130-3	Core 2	96.83	0.33	0.09	<0.63	<0.83	0.02	<0.65	<0.47	1.48	<0.69							
MK	2130-3	Core 2 Re.	94.74	0.89	0.55	0.42	0.20	0.29	0.20	<0.47	4.04	<0.69							
MK	2130-3	Glaze 1	86.03	0.25	2.64	<0.63	0.43	0.03	<0.65	<0.47	14.11	<0.69							
MK	2130-3	Glaze 1 Re.	76.49	0.95	2.44	0.30	0.03	0.16	<0.65	<0.47	19.12	<0.69				0.51			
MK	2130-3	Glaze 2	79.21	0.80	5.87	0.14	0.40	0.25	<0.65	<0.47	16.14	<0.69							
MK	2130-3	Glaze 2 Re.	79.53	0.83	1.19	0.20	<0.83	0.20	0.10	<0.47	17.74	<0.69		0.59					

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2130-3	Interparticle 1	90.67	0.40	0.71	0.08	0.53	0.16	1.39	<0.47	8.00	0.16							
MK	2130-3	Interparticle 1 Re.	89.22	0.64	1.36	0.09	<0.83	0.20	<0.65	<0.47	5.95	<0.69				2.54			
MK	2130-3	Interparticle 2	68.89	0.41	0.62	0.09	5.13	0.85	1.65	<0.47	8.41	<0.69				13.94			
MK	2130-3	Interparticle 2 Re.	93.11	0.85	0.41	0.21	0.11	0.29	0.02	<0.47	4.47	<0.69							
MK	2130-4	Core 1	93.48	0.46	0.36	<0.63	0.13	0.14	0.83	<0.47	5.09	0.12							
MK	2130-4	Core 1 Re.	98.38	0.97	<0.40	0.23	0.11	0.29	<0.65	<0.47	0.72	<0.69							
MK	2130-4	Core 2	94.37	0.42	0.81	<0.63	0.10	0.15	0.26	<0.47	3.00	<0.69							
MK	2130-4	Core 2 Re.	93.59	0.90	0.43	0.14	0.15	0.37	<0.65	<0.47	5.14	<0.69							
MK	2130-4	Glaze 1	79.30	0.76	5.22	0.07	0.60	0.16	0.82	<0.47	15.46	<0.69							
MK	2130-4	Glaze 1 Re.	83.36	0.65	3.00	0.38	<0.83	0.36	<0.65	<0.47	12.69	<0.69							
MK	2130-4	Glaze 2	79.18	0.28	2.45	<0.63	0.51	0.11	0.14	<0.47	17.34	0.05							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2130-4	Glaze 2 Re.	80.75	0.95	6.13	0.29	0.06	0.26	<0.65	<0.47	10.61	<0.69				0.95			
MK	2130-4	Interparticle 1	84.92	0.37	1.80	<0.63	0.77	0.39	1.00	<0.47	10.96	<0.69							
MK	2130-4	Interparticle 1 Re.	85.26	0.65	1.26	0.19	0.05	0.44	6.16	<0.47	7.43	<0.69		0.69					
MK	2130-4	Interparticle 2	95.25	0.45	0.17	<0.63	0.15	0.05	0.68	<0.47	4.16	<0.69							
MK	2130-4	Interparticle 2 Re.	77.37	1.05	7.08	0.32	0.23	0.12	<0.65	<0.47	9.56	<0.69				4.26			
MK	2130-5	Core 1	80.57	<0.29	0.83	<0.63	<0.83	<0.42	19.11	<0.47	2.85	<0.69							
MK	2130-5	Core 1 Re.	89.79	1.13	0.26	0.48	0.09	0.20	<0.65	<0.47	7.67	<0.69		0.47				1.38	
MK	2130-5	Core 2	99.22	0.31	0.08	<0.63	0.09	0.01	0.10	<0.47	0.70	<0.69							
MK	2130-5	Core 2 Re.	96.43	0.91	<0.40	0.28	<0.83	0.24	<0.65	<0.47	0.62	<0.69						1.10	
MK	2130-5	Glaze 1	82.66	<0.29	0.83	<0.63	0.51	<0.42	0.42	<0.47	18.52	<0.69							
MK	2130-5	Glaze 1 Re.	85.95	0.58	0.56	0.12	<0.83	0.13	<0.65	<0.47	11.51	<0.69		1.02				1.21	

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2130-5	Glaze 2	80.56	0.32	4.07	<0.63	0.26	<0.42	0.06	<0.47	15.32	0.12							
MK	2130-5	Glaze 2 Re.	81.88	0.53	1.94	0.26	<0.83	0.13	<0.65	<0.47	13.98	<0.69		0.63				1.14	
MK	2130-5	Interparticle 1	84.14	0.89	1.20	0.24	0.17	0.09	1.82	<0.47	10.80	1.15							
MK	2130-5	Interparticle 1 Re.	79.47	1.11	1.07	0.36	0.01	0.14	<0.65	<0.47	11.73	<0.69		1.33		3.49		1.27	
MK	2130-5	Interparticle 2	92.03	0.34	0.51	0.56	0.27	<0.42	<0.65	<0.47	9.36	<0.69							
MK	2130-5	Interparticle 2 Re.	78.28	0.56	1.38	0.43	0.05	0.30	<0.65	<0.47	14.66	<0.69		0.79		2.73		0.82	
MK	2130-6	Core 1	96.62	0.50	0.54	<0.63	<0.83	0.06	2.07	<0.47	0.97	<0.69							
MK	2130-6	Core 1 Re.	75.47	1.27	<0.40	<0.63	8.35	3.36	2.08	<0.47	11.57	<0.69							
MK	2130-6	Core 2	93.74	0.56	0.61	<0.63	0.21	0.85	1.41	<0.47	3.95	<0.69							
MK	2130-6	Core 2 Re.	98.32	0.89	<0.40	<0.63	<0.83	0.20	<0.65	<0.47	0.85	<0.69							
MK	2130-6	Glaze 1 Re.	83.38	0.77	<0.40	<0.63	4.23	1.48	<0.65	<0.47	7.54	<0.69				2.60			

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2130-6	Glaze 2	93.12	0.49	0.69	<0.63	0.06	0.42	1.38	<0.47	6.69	0.01							
MK	2130-6	Glaze 2 Re.	85.97	0.68	0.85	<0.63	<0.83	0.87	<0.65	<0.47	9.81	<0.69				1.82			
MK	2130-6	Interparticle 1	98.11	0.58	<0.40	<0.63	0.94	<0.42	0.41	<0.47	2.53	<0.69		0.16					
MK	2130-6	Interparticle 1 Re.	67.86	1.16	<0.40	<0.63	9.87	3.96	2.11	<0.47	13.58	<0.69				1.47			
MK	2130-6	Interparticle 2	82.35	0.91	1.00	0.04	<0.83	1.18	6.70	<0.47	10.23	0.07							
MK	2130-6	Interparticle 2 Re.	95.80	0.86	<0.40	<0.63	<0.83	0.24	<0.65	<0.47	0.98	<0.69							
MK	2130-7	Core 1	87.78	0.97	0.64	0.31	0.19	0.17	0.66	<0.47	7.41	0.08							
MK	2130-7	Core 2	96.90	0.72	<0.40	0.13	<0.83	0.32	<0.65	<0.47	0.59	0.07							
MK	2130-7	Glaze 1	74.86	1.09	6.25	0.47	0.06	0.23	0.49	<0.47	16.30	0.08							
MK	2130-7	Glaze 2	75.08	0.78	6.52	0.25	<0.83	0.12	0.16	<0.47	14.33	0.14							
MK	2130-7	Interparticle 1	80.63	1.14	3.92	0.29	0.09	0.20	0.53	<0.47	9.65	0.63							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2130-7	Interparticle 2	97.48	0.60	<0.40	<0.63	<0.83	0.27	0.16	<0.47	0.72	0.04							
MK	2130-8	Core 1	93.29	0.94	0.08	0.33	0.20	0.28	0.56	<0.47	2.66	<0.69							
MK	2130-8	Core 2	96.63	0.99	<0.40	0.32	0.08	0.27	0.08	<0.47	0.82	0.06							
MK	2130-8	Glaze 1	79.16	0.86	3.97	1.42	0.32	0.27	0.34	<0.47	14.47	0.15							
MK	2130-8	Glaze 2	78.18	1.43	4.65	0.36	0.11	0.32	0.64	<0.47	12.09	0.06							
MK	2130-8	Interparticle 1	95.26	0.83	<0.40	0.23	0.01	0.23	0.28	<0.47	0.60	<0.69							
MK	2130-8	Interparticle 2	78.04	0.87	3.64	0.28	0.02	0.14	0.30	<0.47	15.64	<0.69							
MK	2130-9	Core 1	96.11	0.89	<0.40	0.22	0.24	0.28	<0.65	<0.47	0.46	0.07							
MK	2130-9	Glaze 1	63.34	0.69	2.23	<0.63	10.58	4.32	1.05	<0.47	16.87	0.20							
MK	2130-9	Interparticle 1	82.75	1.10	<0.40	<0.63	5.91	2.09	2.28	<0.47	6.08	0.05							
MK	2130-10	Core 1	81.93	1.13	0.06	0.23	4.96	2.22	1.27	<0.47	5.36	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2130-10	Core 2	89.42	0.98	<0.40	0.24	1.17	1.06	1.17	<0.47	5.95	0.01							
MK	2130-10	Glaze 1	88.71	0.91	0.08	0.26	0.76	0.87	0.04	<0.47	7.74	<0.69							
MK	2130-10	Interparticle 1	92.72	0.72	<0.40	0.06	2.50	1.51	0.49	<0.47	3.89	<0.69							
MK	2130-10	Interparticle 2	68.04	1.09	0.43	0.18	10.53	4.11	2.02	<0.47	11.36	0.07							
MK	2345-1	Core 1	99.78	0.93	<0.40	0.28	0.08	0.42	0.51	<0.47	0.45	0.07							
MK	2345-1	Core 2	96.22	0.96	<0.40	0.27	0.10	0.24	0.29	<0.47	0.47	<0.69							
MK	2345-1	Glaze 1	78.87	3.98	0.18	0.30	0.37	3.87	10.89	<0.47	0.93	<0.69							
MK	2345-1	Glaze 2	71.56	3.81	0.01	0.38	2.17	2.95	15.25	<0.47	0.78	<0.69						1.19	
MK	2345-1	Interparticle 1	75.81	6.33	0.36	0.23	1.01	4.73	11.79	<0.47	0.95	<0.69							
MK	2345-1	Interparticle 2	80.87	2.84	0.02	0.21	3.59	1.53	8.99	<0.47	0.60	<0.69							
MK	2345-2	Core 1	67.61	6.10	0.73	0.15	3.98	2.45	15.67	<0.47	0.89	0.10							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2345-2	Core 2	97.59	1.01	<0.40	0.30	0.17	0.33	0.33	<0.47	0.57	<0.69							
MK	2345-2	Glaze 1	70.16	3.91	2.07	0.32	0.85	3.81	14.02	<0.47	1.09	0.05						2.30	
MK	2345-2	Glaze 2	75.50	3.84	0.19	0.21	2.70	4.50	12.13	<0.47	1.17	0.05							
MK	2345-2	Interparticle 1	65.82	5.01	1.21	0.48	7.68	2.88	16.02	<0.47	0.73	0.09							
MK	2345-2	Interparticle 2	92.00	1.57	0.02	0.33	0.48	1.35	4.22	<0.47	0.39	0.07							
MK	2345-3	Core 1	68.33	4.63	0.39	0.34	4.30	3.72	20.23	<0.47	0.53	0.05							
MK	2345-3	Core 2	96.23	1.04	<0.40	0.22	0.43	0.39	0.79	<0.47	0.40	0.07							
MK	2345-3	Glaze 1	76.34	2.26	6.83	0.35	1.97	2.14	8.05	<0.47	1.13	<0.69							
MK	2345-3	Glaze 2	62.81	5.15	0.88	0.44	4.55	4.47	23.96	<0.47	0.52	0.02							
MK	2345-3	Interparticle 1	54.91	6.79	0.26	<0.63	5.84	4.58	28.89	<0.47	0.65	0.16							
MK	2345-3	Interparticle 2	60.51	2.01	1.17	<0.63	0.57	5.31	28.23	<0.47	0.83	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2345-4	Core 1	96.19	0.85	<0.40	0.33	0.09	0.27	0.14	<0.47	0.56	<0.69							
MK	2345-4	Core 2	98.57	0.87	<0.40	0.26	0.09	0.36	0.67	<0.47	0.63	<0.69							
MK	2345-4	Glaze 1	75.89	3.75	0.62	0.27	1.44	2.76	11.36	<0.47	1.18	0.04							
MK	2345-4	Glaze 2	66.05	2.07	3.88	0.14	<0.83	1.52	26.86	<0.47	1.51	0.12							
MK	2345-4	Interparticle 1	84.26	2.92	0.50	0.35	0.62	1.03	7.58	<0.47	0.65	<0.69							
MK	2345-4	Interparticle 2	82.47	3.75	4.51	0.46	0.24	1.54	8.72	<0.47	1.07	<0.69							
MK	2345-5	Core 1	91.74	0.68	0.24	0.01	2.33	0.93	0.44	<0.47	3.01	0.09							
MK	2345-5	Core 2	87.57	0.92	0.50	0.17	1.76	1.34	3.24	<0.47	5.08	0.20							
MK	2345-5	Glaze 1	71.30	0.55	2.22	0.01	4.70	3.02	0.04	<0.47	18.66	0.10							
MK	2345-5	Glaze 2	72.03	1.05	2.00	0.15	9.59	2.54	1.17	<0.47	11.04	0.14							
MK	2345-5	Interparticle 1	69.05	0.87	4.59	0.07	6.29	3.69	1.10	<0.47	14.05	0.30							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2345-5	Interparticle 2	84.92	0.91	1.07	0.18	0.76	1.10	0.31	<0.47	8.36	0.11							
MK	2345-6	Core 1	87.67	0.88	1.42	0.17	3.38	0.84	0.76	<0.47	3.21	0.10							
MK	2345-6	Core 2	80.83	0.67	1.49	0.24	6.28	1.77	0.89	<0.47	5.48	0.41							
MK	2345-6	Glaze 1	73.56	0.74	3.93	0.31	10.31	2.74	0.78	<0.47	7.53	0.31							
MK	2345-6	Glaze 2	70.07	0.81	5.39	0.28	8.92	3.57	0.67	<0.47	10.17	0.35							
MK	2345-6	Interparticle 1	68.77	0.95	6.20	0.36	9.16	3.66	0.99	<0.47	7.63	0.40							
MK	2345-6	Interparticle 2	75.82	0.74	3.85	0.26	6.49	2.88	0.63	<0.47	10.39	0.46							
MK	2345-7	Core 1	79.25	1.14	1.48	0.26	4.71	1.67	1.99	<0.47	7.32	3.05							
MK	2345-7	Core 2	94.89	0.91	0.44	0.26	2.10	0.76	0.15	<0.47	2.76	0.10							
MK	2345-7	Glaze 1	78.47	0.98	0.94	0.38	0.63	0.64	6.98	<0.47	7.76	0.25							
MK	2345-7	Glaze 2	77.90	0.92	4.46	0.21	0.17	1.32	0.31	<0.47	13.83	0.20							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2345-7	Interparticle 1	93.11	0.86	0.13	0.29	0.53	0.43	0.06	<0.47	3.66	0.02							
MK	2345-7	Interparticle 2	86.88	1.05	0.90	0.30	0.81	1.21	0.87	<0.47	5.32	0.08							
MK	2345-8	Core 1	81.93	1.12	0.42	0.08	7.11	2.35	0.13	<0.47	7.39	<0.69							
MK	2345-8	Core 2	81.28	1.97	1.51	0.33	1.73	1.31	2.13	<0.47	10.08	<0.69							
MK	2345-8	Glaze 1	78.57	0.85	4.52	0.19	0.51	1.72	0.14	<0.47	13.35	0.04							
MK	2345-8	Glaze 2	84.88	0.95	0.48	0.17	0.48	0.99	0.27	<0.47	13.93	<0.69							
MK	2345-8	Interparticle 1	76.90	0.97	1.47	0.06	3.60	3.49	0.26	<0.47	12.52	0.05							
MK	2345-8	Interparticle 2	86.56	1.20	0.21	0.06	0.23	1.03	0.37	<0.47	8.72	0.02							
MK	2345-9	Core 1	72.11	1.26	2.80	0.14	7.33	3.20	1.23	<0.47	11.00	0.34							
MK	2345-9	Core 2	68.75	2.17	0.88	0.19	10.93	3.72	1.12	<0.47	13.61	0.27							
MK	2345-9	Glaze 1	65.35	1.07	5.47	0.31	13.01	3.35	1.15	<0.47	10.24	0.58							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2345-9	Glaze 2	73.59	0.97	1.45	0.14	7.98	2.94	0.98	<0.47	12.75	0.15							
MK	2345-9	Interparticle 1	84.31	0.99	1.69	0.16	5.07	1.98	1.04	<0.47	6.93	0.18							
MK	2345-9	Interparticle 2	69.43	0.91	1.77	0.07	9.17	3.47	0.82	<0.47	13.13	0.23							
MK	2345-10	Core 1	89.77	1.02	0.52	0.11	0.71	0.49	0.73	<0.47	3.82	<0.69							
MK	2345-10	Core 2	79.55	1.27	2.24	0.27	2.38	0.72	5.77	<0.47	5.65	0.06							
MK	2345-10	Glaze 1	58.14	1.37	14.67	0.07	2.84	0.78	1.74	<0.47	23.21	<0.69							
MK	2345-10	Glaze 2	66.55	1.21	8.54	0.14	1.04	0.88	1.41	<0.47	18.51	<0.69							
MK	2345-10	Interparticle 1	61.59	2.38	7.33	0.39	3.92	2.33	3.63	<0.47	20.00	0.06							
MK	2345-10	Interparticle 2	59.60	2.53	16.04	0.70	4.39	1.62	2.50	<0.47	14.92	0.15							
MK	2379-1	Core 1	88.86	0.85	2.26	0.04	3.60	0.88	0.04	<0.47	2.10	<0.69							
MK	2379-1	Core 2	93.42	0.57	1.21	0.58	<0.83	0.25	0.70	<0.47	2.35	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2379-1	Glaze 1	70.96	0.84	9.74	0.36	0.25	1.79	9.23	<0.47	6.82	0.15							
MK	2379-1	Glaze 2	79.29	0.78	3.99	0.11	<0.83	<0.42	0.76	<0.47	14.61	0.03							
MK	2379-1	Interparticle 1	83.28	0.60	1.88	0.28	6.09	1.79	2.61	<0.47	4.39	<0.69							
MK	2379-1	Interparticle 2	87.78	0.62	2.61	0.21	<0.83	1.18	0.54	<0.47	4.44	0.03							
MK	2379-2	Core 1	95.30	0.81	<0.40	0.21	0.04	0.30	0.18	<0.47	0.80	0.07							
MK	2379-2	Core 2	89.64	1.31	0.36	0.48	0.50	0.43	2.90	<0.47	3.28	0.07							
MK	2379-2	Glaze 1	88.62	1.07	0.70	0.34	0.20	0.31	0.91	<0.47	10.13	0.15							
MK	2379-2	Glaze 2	83.70	1.60	0.81	0.40	0.18	0.40	0.99	<0.47	14.49	0.24							
MK	2379-2	Interparticle 1	93.53	0.97	<0.40	0.28	0.14	0.26	0.48	<0.47	2.32	0.06							
MK	2379-2	Interparticle 2	82.24	0.84	0.76	0.28	0.09	0.04	0.27	<0.47	12.62	0.02							
MK	2379-3	Core 1	97.62	0.82	<0.40	0.17	0.01	0.29	0.15	<0.47	0.56	0.06							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2379-3	Core 2	94.62	0.65	0.28	<0.63	<0.83	0.28	0.53	<0.47	3.01	0.11							
MK	2379-3	Glaze 1	85.74	0.85	0.66	0.32	0.21	0.43	0.17	<0.47	12.02	0.01							
MK	2379-3	Glaze 2	86.76	0.56	0.91	0.19	0.13	0.32	0.31	<0.47	9.73	0.21							
MK	2379-3	Interparticle 1	95.73	0.83	0.16	0.09	0.17	0.28	0.33	<0.47	2.15	0.05							
MK	2379-3	Interparticle 2	98.28	0.89	0.05	0.32	0.05	0.29	0.17	<0.47	2.33	<0.69							
MK	2379-4	Core 1	97.67	0.90	<0.40	0.33	0.10	0.35	0.01	<0.47	0.65	<0.69							
MK	2379-4	Core 2	96.29	0.66	<0.40	0.07	0.34	<0.42	0.12	<0.47	0.44	0.02							
MK	2379-4	Glaze 1	74.52	0.88	2.20	0.17	0.01	0.16	0.47	<0.47	23.96	0.10							
MK	2379-4	Glaze 2	72.41	0.79	1.23	0.20	<0.83	0.30	0.13	<0.47	27.63	0.02							
MK	2379-4	Interparticle 1	89.75	0.83	0.03	0.16	1.99	1.01	0.13	<0.47	4.16	<0.69							
MK	2379-4	Interparticle 2	83.03	1.01	0.39	0.15	3.98	2.10	1.60	<0.47	6.91	0.02							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2379-5	Core 1	96.72	0.81	<0.40	0.25	0.06	0.28	0.14	<0.47	1.19	0.02							
MK	2379-5	Core 2	95.82	1.10	<0.40	0.42	0.13	0.20	0.37	<0.47	2.58	<0.69		0.35				1.35	
MK	2379-5	Glaze 1	71.45	1.18	0.54	0.32	0.07	0.13	0.17	<0.47	25.54	0.01							
MK	2379-5	Glaze 2	69.09	0.89	<0.40	0.23	<0.83	0.13	0.09	<0.47	28.33	0.09		1.62				1.10	
MK	2379-5	Interparticle 1	80.79	1.37	0.11	0.39	<0.83	0.18	1.17	<0.47	13.19	0.10		1.72				2.42	
MK	2379-5	Interparticle 2	82.54	0.94	<0.40	0.32	0.09	0.12	0.27	<0.47	11.89	0.01		1.40				1.37	
MK	2379-6	Core 1	90.85	0.79	<0.40	0.19	0.31	0.53	5.03	<0.47	0.67	<0.69							
MK	2379-6	Core 2	78.66	0.89	0.71	0.33	0.65	1.68	16.06	<0.47	2.47	<0.69							
MK	2379-6	Glaze 1	76.14	0.79	0.31	0.22	0.05	0.22	2.44	<0.47	16.91	0.30							
MK	2379-6	Glaze 2	78.96	0.87	0.84	0.33	0.04	0.19	2.74	<0.47	13.33	0.21							
MK	2379-6	Interparticle 1	78.03	0.68	0.20	0.12	0.42	0.92	15.61	<0.47	4.30	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2379-6	Interparticle 2	80.93	0.92	0.71	0.32	0.27	0.28	3.15	<0.47	11.07	<0.69							
MK	2379-7	Core 1	86.72	1.72	1.09	0.50	0.36	0.43	3.93	<0.47	4.21	<0.69							
MK	2379-7	Core 2	95.18	1.02	<0.40	0.39	0.19	0.31	0.74	<0.47	0.87	0.01							
MK	2379-7	Glaze 1	79.31	1.47	0.24	0.12	0.13	0.30	1.86	<0.47	17.17	<0.69							
MK	2379-7	Glaze 2	75.51	1.20	1.74	0.25	0.19	0.20	0.59	<0.47	19.36	<0.69							
MK	2379-7	Interparticle 1	90.03	1.55	0.34	0.26	0.22	0.42	2.70	<0.47	3.14	0.02							
MK	2379-7	Interparticle 2	96.43	0.85	<0.40	0.24	0.01	0.24	0.02	<0.47	0.79	<0.69							
MK	2379-8	Core 1	94.79	0.72	<0.40	0.14	0.45	0.37	0.27	<0.47	0.45	0.79							
MK	2379-8	Core 2	66.00	1.64	1.46	0.28	7.91	2.91	3.09	<0.47	3.21	11.21							
MK	2379-8	Glaze 1	74.60	1.26	3.12	0.30	0.22	0.23	1.29	<0.47	13.26	4.14							
MK	2379-8	Glaze 2	81.72	0.52	0.79	0.04	0.19	0.41	0.02	<0.47	14.31	3.29							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2379-8	Interparticle 1	77.63	0.84	2.66	0.10	8.13	1.73	1.51	<0.47	3.42	3.73							
MK	2379-8	Interparticle 2	85.12	1.37	0.43	0.32	0.47	0.60	1.69	<0.47	4.65	5.16							
MK	2379-9	Core 1	95.21	0.90	<0.40	0.28	0.11	0.29	0.22	<0.47	0.72	0.10							
MK	2379-9	Core 2	96.48	0.74	<0.40	0.11	0.71	0.50	0.26	<0.47	0.77	0.36							
MK	2379-9	Glaze 1	79.74	0.71	1.30	<0.63	<0.83	0.33	0.96	<0.47	13.54	3.56							
MK	2379-9	Glaze 2	69.74	1.53	6.90	0.43	0.07	1.03	1.59	<0.47	13.61	3.49							
MK	2379-9	Interparticle 1	69.28	3.47	0.84	<0.63	7.53	6.24	1.50	<0.47	3.49	7.67							
MK	2379-9	Interparticle 2	86.25	1.09	0.33	0.22	4.92	2.22	1.17	<0.47	2.04	3.48							
MK	2379-10	Core 1	95.11	0.93	<0.40	0.31	<0.83	0.27	0.15	<0.47	0.65	0.03							
MK	2379-10	Core 2	96.44	0.69	<0.40	0.09	<0.83	0.30	0.10	<0.47	0.73	<0.69							
MK	2379-10	Glaze 1	79.01	0.97	0.73	0.26	0.37	0.34	0.42	<0.47	20.61	0.07							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2379-10	Glaze 2	84.90	0.91	0.48	0.24	0.07	0.22	0.20	<0.47	12.58	0.21							
MK	2379-10	Interparticle 1	90.26	1.13	0.18	0.33	0.39	0.45	2.27	<0.47	3.96	0.06							
MK	2379-10	Interparticle 2	87.61	0.66	0.24	0.08	<0.83	0.18	0.22	<0.47	9.81	<0.69							
MK	2383-1	Core 1	96.01	0.78	<0.40	0.19	<0.83	0.34	0.01	<0.47	0.63	<0.69							
MK	2383-1	Core 2	92.93	1.03	0.05	0.33	<0.83	0.27	0.95	<0.47	3.35	<0.69							
MK	2383-1	Glaze 1	86.38	1.21	0.31	0.37	0.07	0.24	0.14	<0.47	11.23	<0.69							
MK	2383-1	Glaze 2	86.30	3.13	0.24	0.35	0.12	0.20	0.06	<0.47	10.28	0.03							
MK	2383-1	Interparticle 1	92.53	0.83	0.02	<0.63	<0.83	0.27	0.51	<0.47	6.73	0.01							
MK	2383-1	Interparticle 2	85.39	1.24	0.52	0.27	0.15	0.38	0.90	<0.47	13.24	0.12							
MK	2383-2	Core 1	89.81	1.29	0.07	0.24	1.32	0.58	4.45	<0.47	2.83	<0.69							
MK	2383-2	Core 2	63.97	0.82	0.69	0.12	5.05	4.68	24.79	<0.47	2.10	0.10							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2383-2	Glaze 1	66.96	0.90	0.43	0.11	4.33	0.55	4.79	<0.47	20.45	<0.69							
MK	2383-2	Glaze 2	73.27	0.88	0.40	0.16	0.16	0.41	4.70	<0.47	22.58	0.05							
MK	2383-2	Interparticle 1	96.90	2.15	<0.40	0.40	0.25	0.30	0.34	<0.47	1.08	<0.69							
MK	2383-2	Interparticle 2	79.37	2.05	0.36	0.24	1.10	0.44	10.35	<0.47	6.28	<0.69							
MK	2383-3	Core 1	83.94	1.72	0.37	0.29	0.65	0.91	1.69	<0.47	8.22	0.05							
MK	2383-3	Core 2	97.76	0.83	<0.40	0.20	0.05	0.30	0.21	<0.47	0.50	<0.69							
MK	2383-3	Glaze 1	74.63	0.80	2.14	0.17	0.13	0.40	0.10	<0.47	22.78	0.04							
MK	2383-3	Glaze 2	87.75	1.11	<0.40	0.12	<0.83	0.38	<0.65	<0.47	10.08	0.06							
MK	2383-3	Interparticle 1	83.93	1.14	1.07	0.23	0.42	0.58	0.39	<0.47	12.78	<0.69							
MK	2383-3	Interparticle 2	95.56	1.42	<0.40	0.09	0.10	0.32	0.12	<0.47	0.62	0.03							
MK	2383-4	Core 1	94.34	0.91	<0.40	0.26	0.72	0.54	0.15	<0.47	2.23	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2383-4	Core 2	95.20	0.88	<0.40	0.26	0.40	0.33	<0.65	<0.47	1.01	<0.69							
MK	2383-4	Glaze 1	73.00	1.43	1.00	0.11	6.23	2.25	1.38	<0.47	13.19	0.01							
MK	2383-4	Glaze 2	73.01	0.82	0.65	0.26	0.14	0.13	<0.65	<0.47	23.07	0.11							
MK	2383-4	Interparticle 1	97.73	0.95	0.15	0.17	0.25	0.50	0.44	<0.47	1.52	0.15							
MK	2383-4	Interparticle 2	89.21	0.84	0.10	0.15	0.19	0.38	0.32	<0.47	8.13	<0.69							
MK	2383-5	Core 1	97.47	0.95	<0.40	0.33	0.09	0.31	<0.65	<0.47	0.78	<0.69					0.27		
MK	2383-5	Core 2	72.87	2.79	0.67	0.23	5.08	2.37	1.40	<0.47	13.71	<0.69					2.76		
MK	2383-5	Glaze 1	94.47	1.08	0.07	0.33	0.11	0.31	0.14	<0.47	3.05	0.06					1.11		
MK	2383-5	Glaze 2	71.33	0.84	0.35	0.13	<0.83	0.14	0.24	<0.47	5.98	0.11					2.05		
MK	2383-5	Interparticle 1	95.05	0.91	<0.40	0.22	0.24	0.35	0.01	<0.47	1.03	0.04					0.58		
MK	2383-5	Interparticle 2	56.88	1.11	0.54	<0.63	4.51	0.82	0.66	<0.47	8.51	<0.69					16.15		

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2383-6	Core 1	51.58	1.03	36.10	0.12	3.37	0.34	0.99	<0.47	6.39	0.13		0.91					
MK	2383-6	Core 2	60.22	1.69	26.06	0.91	1.78	0.75	1.26	<0.47	6.75	<0.69		0.44					
MK	2383-6	Glaze 1	82.69	1.81	1.81	0.41	0.26	0.94	1.44	<0.47	10.41	0.02		0.14					
MK	2383-6	Glaze 2	58.07	1.25	28.09	0.18	3.25	0.49	1.02	<0.47	7.29	0.01		0.41					
MK	2383-6	Interparticle 1	64.05	1.46	21.72	0.29	3.63	0.62	0.88	<0.47	6.86	<0.69		0.13					
MK	2383-6	Interparticle 2	58.03	1.74	19.15	0.30	5.05	1.59	1.54	<0.47	13.30	<0.69		0.39					
MK	2435-1	Core 1	96.83	0.63	<0.40	0.14	0.14	0.28	0.31	<0.47	0.45	0.03							
MK	2435-1	Core 2	93.35	0.74	<0.40	0.19	0.94	0.37	2.61	<0.47	0.49	<0.69							
MK	2435-1	Glaze 1	74.71	0.59	2.99	<0.63	4.12	1.80	6.74	<0.47	7.88	0.09							
MK	2435-1	Glaze 2	73.98	1.27	1.67	0.28	0.14	1.46	16.96	<0.47	4.59	0.02							
MK	2435-1	Interparticle 1	86.39	0.80	0.13	0.20	3.92	0.66	5.79	<0.47	1.07	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2435-1	Interparticle 2	89.27	0.85	0.13	0.11	1.49	0.73	5.84	<0.47	1.22	0.15							
MK	2435-2	Core 1	98.44	0.84	<0.40	0.31	0.03	0.31	0.01	<0.47	0.63	<0.69							
MK	2435-2	Core 2	94.91	1.04	<0.40	0.43	0.11	0.35	0.15	<0.47	0.40	0.08							
MK	2435-2	Glaze 1	87.82	0.89	1.18	0.20	0.14	0.85	0.50	<0.47	7.10	0.06							
MK	2435-2	Glaze 2	78.75	1.15	1.39	0.28	0.07	0.25	1.53	<0.47	17.92	0.04							
MK	2435-2	Interparticle 1	96.40	0.90	<0.40	0.27	0.05	0.30	0.09	<0.47	0.58	0.05							
MK	2435-2	Interparticle 2	88.83	1.24	0.18	0.06	2.42	1.70	0.93	<0.47	3.32	0.06							
MK	2435-3	Core 1	99.64	0.92	<0.40	0.26	0.13	0.24	<0.65	<0.47	0.57	0.05							
MK	2435-3	Core 2	97.28	0.98	0.05	0.20	0.05	0.26	0.30	<0.47	3.44	<0.69							
MK	2435-3	Glaze 1	97.57	1.08	<0.40	0.31	0.15	0.36	<0.65	<0.47	2.45	<0.69							
MK	2435-3	Glaze 2	81.49	0.96	0.57	0.25	<0.83	0.18	0.07	<0.47	18.88	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2435-3	Interparticle 1	99.17	0.71	<0.40	0.11	<0.83	0.34	0.03	<0.47	0.55	0.11							
MK	2435-3	Interparticle 2	92.11	1.03	0.43	0.34	0.10	0.26	0.81	<0.47	6.04	0.10							
MK	2435-4	Core 1	77.22	0.73	0.03	<0.63	3.23	5.90	5.05	<0.47	9.09	0.14							
MK	2435-4	Core 2	96.40	0.84	<0.40	0.19	<0.83	0.29	<0.65	<0.47	0.52	0.03							
MK	2435-4	Glaze 1	84.62	1.00	0.28	0.23	0.11	0.52	0.20	<0.47	15.64	<0.69							
MK	2435-4	Glaze 2	89.28	0.75	<0.40	0.11	0.04	0.49	<0.65	<0.47	6.55	<0.69							
MK	2435-4	Interparticle 1	83.20	0.91	0.44	0.22	2.67	4.17	0.25	<0.47	8.53	<0.69							
MK	2435-4	Interparticle 2	90.82	0.97	<0.40	0.18	0.17	0.57	0.57	<0.47	6.12	0.06							
MK	2435-5	Core 1	90.23	1.08	1.04	0.37	0.20	0.42	0.47	<0.47	3.38	0.01							
MK	2435-5	Core 2	95.63	0.96	0.24	0.33	0.08	0.28	2.51	<0.47	0.82	0.04							
MK	2435-5	Glaze 1	79.77	1.40	2.59	0.24	0.24	0.35	0.33	<0.47	16.70	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	2435-5	Glaze 2	78.58	0.82	3.67	0.19	0.28	0.25	0.86	<0.47	12.88	0.03							
MK	2435-5	Interparticle 1	90.27	1.04	0.31	0.28	0.10	0.34	0.73	<0.47	5.31	0.07							
MK	2435-5	Interparticle 2	87.53	1.05	1.29	0.23	3.06	1.21	0.89	<0.47	4.23	0.11							
MK	54.00.75-1	Core 1	61.87	<0.29	18.09	3.01	<0.83	<0.42	5.19	<0.47	5.94	<0.69				5.90			
MK	54.00.75-1	Core 2	96.71	0.86	<0.40	0.25	<0.83	0.31	0.06	<0.47	0.28	0.05		0.30					
MK	54.00.75-1	Glaze 1	78.25	0.47	0.32	6.70	<0.83	0.19	<0.65	<0.47	11.77	<0.69		0.76					
MK	54.00.75-1	Glaze 2	59.95	0.72	2.09	11.02	0.48	0.53	8.76	<0.47	8.05	1.70		2.19		4.52			
MK	54.00.75-1	Interparticle 1	88.92	0.82	0.07	2.80	<0.83	0.24	<0.65	<0.47	5.53	<0.69							
MK	54.00.75-1	Interparticle 2	91.87	<0.29	<0.40	3.59	<0.83	0.38	0.88	<0.47	1.17	<0.69		0.88					
MK	54.00.75-2	Core 1	94.82	0.62	<0.40	0.15	<0.83	0.35	0.58	<0.47	0.44	<0.69		0.25					
MK	54.00.75-2	Core 2	96.44	0.56	<0.40	<0.63	<0.83	0.36	0.27	<0.47	0.49	0.04		0.23					

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	54.00.75-2	Glaze 1	71.41	0.59	0.75	19.39	<0.83	0.28	3.11	<0.47	1.73	0.51		4.22					
MK	54.00.75-2	Glaze 2	73.26	0.85	0.22	18.82	<0.83	0.28	3.15	<0.47	1.14	0.53		2.24					
MK	54.00.75-2	Interparticle 1	68.35	0.56	0.82	22.93	<0.83	0.19	2.61	<0.47	2.03	0.46		4.62					
MK	54.00.75-2	Interparticle 2	83.16	0.97	6.95	<0.63	<0.83	0.20	1.57	<0.47	1.34	0.35		1.53		3.93			
MK	54.00.75-3	Core 1	79.42	0.67	0.18	12.37	<0.83	0.40	0.13	<0.47	5.18	0.34		1.68					
MK	54.00.75-3	Core 2	95.83	0.87	<0.40	0.35	<0.83	0.42	0.28	<0.47	0.43	0.03		0.12					
MK	54.00.75-3	Glaze 1	58.60	0.40	<0.40	21.79	1.06	0.48	2.99	<0.47	2.02	0.86		3.30		8.50			
MK	54.00.75-3	Glaze 2	62.40	0.40	0.12	24.28	<0.83	0.37	0.11	<0.47	8.77	0.53		4.32					
MK	54.00.75-3	Interparticle 1	57.65	0.73	0.97	23.42	1.46	0.65	4.32	<0.47	2.69	1.07		4.89		2.15			
MK	54.00.75-3	Interparticle 2	75.96	0.44	0.07	14.73	<0.83	0.40	0.01	<0.47	4.85	0.30		2.55		0.69			
MK	54.00.75-4	Core 1	74.02	1.25	0.72	0.97	2.98	2.49	4.28	<0.47	3.39	10.53		0.18					

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	54.00.75-4	Core 2	86.37	0.99	0.11	2.08	0.69	0.36	2.21	<0.47	1.86	4.94		0.35					
MK	54.00.75-4	Glaze 1	76.53	0.59	0.23	3.28	<0.83	0.61	2.57	<0.47	3.15	16.05							
MK	54.00.75-4	Glaze 2	76.68	0.52	0.55	0.62	0.13	0.61	0.44	<0.47	16.69	4.86		0.19					
MK	54.00.75-4	Interparticle 1	64.70	2.35	1.63	8.11	0.59	0.91	6.29	<0.47	4.30	10.69		0.48					
MK	54.00.75-4	Interparticle 2	71.09	0.64	0.47	0.61	<0.83	0.57	3.37	<0.47	2.27	18.33		0.47					
MK	54.00.75-5	Core 1	83.29	0.37	0.99	2.31	<0.83	0.24	2.44	<0.47	0.50	5.92		0.56		3.38			
MK	54.00.75-5	Core 2	71.44	0.55	0.73	2.19	<0.83	0.40	2.30	<0.47	1.92	17.87		0.55					
MK	54.00.75-5	Glaze 1	69.57	1.57	<0.40	10.48	1.53	0.66	4.93	<0.47	2.35	8.75		1.47					
MK	54.00.75-5	Glaze 2	78.44	0.46	1.65	1.17	<0.83	0.35	1.88	<0.47	0.76	12.14		0.03		3.11			
MK	54.00.75-5	Interparticle 1	65.18	<0.29	0.30	2.73	<0.83	0.20	1.76	<0.47	0.93	28.55			0.25	0.10			
MK	54.00.75-5	Interparticle 2	81.14	0.42	0.83	2.68	<0.83	0.46	2.34	<0.47	1.55	8.36							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	54.00.75-6	Core 1	52.84	0.40	0.25	1.67	0.10	0.87	8.44	0.20	2.22	32.92		0.31					
MK	54.00.75-6	Core 2	75.24	0.48	<0.40	1.85	0.43	0.92	3.73	0.08	1.22	16.73		0.59					
MK	54.00.75-6	Glaze 1	73.26	0.62	0.36	1.03	<0.83	0.48	4.82	<0.47	<0.85	14.33		1.64		3.46			
MK	54.00.75-6	Glaze 2	86.83	0.59	0.06	1.32	0.05	0.58	1.80	0.13	0.59	8.51		1.09					
MK	54.00.75-6	Interparticle 1	67.17	0.54	0.34	1.92	<0.83	0.96	5.25	0.09	1.63	22.53		0.63					
MK	54.00.75-6	Interparticle 2	68.62	0.51	0.36	3.13	1.08	0.66	4.05	<0.47	1.03	16.80		0.54		3.21			
MK	54.00.75-7	Core 1	94.86	0.78	<0.40	0.17	0.15	0.35	0.43	<0.47	0.78	<0.69							
MK	54.00.75-7	Core 2	97.93	0.91	<0.40	0.39	0.05	0.26	0.26	<0.47	0.77	<0.69		0.23					
MK	54.00.75-7	Glaze 1	84.87	0.85	0.08	3.06	0.01	0.48	<0.65	<0.47	10.09	<0.69		1.05					
MK	54.00.75-7	Glaze 2	89.99	0.73	0.05	0.29	<0.83	0.42	<0.65	<0.47	11.26	<0.69							
MK	54.00.75-7	Interparticle 1	93.99	1.16	0.31	0.38	0.36	0.39	1.40	<0.47	2.18	<0.69		0.16					

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	54.00.75-7	Interparticle 2	92.83	1.77	<0.40	0.35	0.42	0.50	0.31	<0.47	3.50	<0.69		0.24					
MK	54.00.75-8	Core 1	94.27	0.88	<0.40	0.48	0.12	0.28	0.35	<0.47	0.68	<0.69		0.50					
MK	54.00.75-8	Core 2	98.46	0.95	<0.40	0.25	<0.83	0.32	<0.65	<0.47	0.32	<0.69		0.13					
MK	54.00.75-8	Glaze 1	88.01	1.05	<0.40	0.91	<0.83	0.30	0.13	<0.47	0.60	<0.69		0.23		8.77			
MK	54.00.75-8	Glaze 2	97.90	1.02	<0.40	0.32	0.04	0.28	0.21	<0.47	0.45	<0.69		0.33					
MK	54.00.75-8	Interparticle 1	96.09	0.89	<0.40	<0.63	<0.83	0.32	0.19	<0.47	0.55	<0.69		0.14					
MK	54.00.75-8	Interparticle 2	96.94	0.81	<0.40	0.20	<0.83	0.37	0.23	<0.47	0.31	<0.69							
MK	54.00.75-9	Core 1	96.03	1.06	<0.40	0.23	0.72	0.43	1.42	<0.47	0.57	<0.69							
MK	54.00.75-9	Core 2	97.43	0.99	<0.40	0.69	0.19	0.30	<0.65	<0.47	0.51	0.36		0.17					
MK	54.00.75-9	Glaze 1	88.64	0.55	<0.40	0.39	0.52	0.35	<0.65	<0.47	1.67	2.59		0.75		4.55			
MK	54.00.75-9	Glaze 2	65.48	0.61	0.17	12.25	1.83	0.75	4.88	<0.47	3.26	9.75		3.51					

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	54.00.75-9	Interparticle 1	92.73	1.04	<0.40	0.20	0.65	0.41	1.29	<0.47	0.60	<0.69		0.45					
MK	54.00.75-9	Interparticle 2	58.61	1.26	0.22	13.37	2.07	0.80	<0.65	<0.47	3.67	9.43		3.66		6.92			
MK	54.00.75-10	Core 1	70.60	1.06	0.76	2.74	0.44	0.38	3.31	<0.47	1.13	12.72		0.63		6.22			
MK	54.00.75-10	Core 2	76.28	1.96	0.05	0.80	0.01	0.24	1.90	<0.47	1.49	8.65		0.74		7.89			
MK	54.00.75-10	Glaze 1	89.95	0.70	<0.40	1.12	<0.83	0.34	<0.65	<0.47	0.38	2.79		0.83		3.74			
MK	54.00.75-10	Glaze 2	89.45	1.42	0.03	0.23	<0.83	0.42	<0.65	<0.47	1.35	1.14		0.64		5.32			
MK	54.00.75-10	Interparticle 1	64.96	1.46	0.72	3.04	0.68	0.42	<0.65	<0.47	0.48	17.32		1.15		9.77			
MK	54.00.75-10	Interparticle 2	92.65	2.19	0.02	0.21	0.20	0.34	<0.65	<0.47	1.49	0.29		0.41					
MK	54.00.79?-1	Core 1	94.54	0.94	<0.40	0.20	1.61	0.40	<0.65	<0.47	1.61	<0.69		0.29					
MK	54.00.79?-1	Core 2	83.58	0.94	0.99	0.33	0.67	0.86	<0.65	<0.47	13.21	<0.69		1.23					
MK	54.00.79?-1	Glaze 1	80.24	1.50	0.79	0.29	0.27	0.52	<0.65	<0.47	14.30	<0.69		1.49		0.58			

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	54.00.79?-1	Glaze 2	77.97	0.74	1.65	0.29	0.37	0.51	<0.65	<0.47	16.02	<0.69		1.71		0.73			
MK	54.00.79?-1	Interparticle 1	80.00	1.27	0.99	0.23	8.85	2.07	<0.65	<0.47	6.75	<0.69		1.02					
MK	54.00.79?-1	Interparticle 2	82.04	0.88	0.98	0.14	0.68	0.96	<0.65	<0.47	12.49	<0.69		1.15		0.69			
MK	54.00.79?-2	Core 1	66.84	0.70	4.84	0.16	12.83	2.33	<0.65	<0.47	13.60	<0.69		1.59					
MK	54.00.79?-2	Core 2	77.43	0.99	1.11	0.14	10.05	2.10	<0.65	<0.47	7.48	<0.69		0.96					
MK	54.00.79?-2	Glaze 1	80.04	0.90	0.81	0.35	0.30	0.71	<0.65	<0.47	12.87	<0.69		1.46		2.59			
MK	54.00.79?-2	Glaze 2	75.54	0.68	2.14	0.27	0.28	0.38	<0.65	<0.47	16.32	<0.69		1.75		2.65			
MK	54.00.79?-2	Interparticle 1	86.83	0.94	0.57	0.40	0.64	0.61	<0.65	<0.47	7.12	<0.69		0.93		1.96			
MK	54.00.79?-2	Interparticle 2	89.19	0.61	0.66	0.03	0.44	0.51	<0.65	<0.47	7.98	<0.69		0.63					
MK	54.00.79?-3	Core 1	91.25	0.88	0.02	0.07	0.48	0.44	0.13	<0.47	4.95	<0.69		0.82		0.96			
MK	54.00.79?-3	Core 2	89.66	0.78	0.24	0.18	0.14	0.37	0.16	<0.47	5.30	<0.69		0.83					

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	54.00.79?-3	Glaze 1	77.83	0.67	1.28	0.17	0.33	0.47	0.33	<0.47	14.11	<0.69		2.60		2.21			
MK	54.00.79?-3	Glaze 2	75.77	0.90	2.75	0.19	0.25	0.44	0.18	<0.47	12.27	<0.69		2.60		4.65			
MK	54.00.79?-3	Interparticle 1	72.84	1.13	1.10	0.15	10.62	2.11	1.08	<0.47	9.96	<0.69		2.40					
MK	54.00.79?-3	Interparticle 2	80.87	1.03	1.35	0.32	0.68	1.39	0.63	<0.47	10.22	<0.69		2.02		1.48			
MK	54.00.79?-4	Core 1	87.53	0.78	0.97	0.18	4.45	0.77	<0.65	<0.47	3.73	<0.69		0.88		0.71			
MK	54.00.79?-4	Core 2	77.71	0.94	1.76	0.07	7.88	1.81	1.23	<0.47	7.10	<0.69		0.46		1.03			
MK	54.00.79?-4	Glaze 1	75.36	0.78	4.86	0.17	0.24	0.58	<0.65	<0.47	14.23	<0.69		3.40		0.37			
MK	54.00.79?-4	Glaze 2	74.25	0.89	2.27	0.41	0.12	0.36	<0.65	<0.47	16.15	<0.69		1.85		3.69			
MK	54.00.79?-4	Interparticle 1	80.39	0.77	4.31	0.23	1.20	1.37	<0.65	<0.47	7.49	<0.69		2.30		1.94			
MK	54.00.79?-4	Interparticle 2	71.37	1.17	1.87	<0.63	10.66	2.75	<0.65	<0.47	8.86	<0.69		1.05		2.26			
MK	54.00.79?-5	Core 1	96.20	0.97	<0.40	0.29	0.08	0.28	0.04	<0.47	0.32	<0.69		0.17					

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	54.00.79?-5	Core 2	96.05	1.20	0.10	0.26	0.35	0.35	0.20	<0.47	0.54	<0.69		0.29					
MK	54.00.79?-5	Glaze 1	76.81	1.37	0.90	0.69	0.25	0.67	0.69	<0.47	13.00	<0.69		3.46		2.15			
MK	54.00.79?-5	Glaze 2	84.80	0.65	0.18	0.10	0.14	0.31	0.07	<0.47	9.48	<0.69		1.72		2.56			
MK	54.00.79?-5	Interparticle 1	86.67	0.71	0.22	0.10	0.14	0.50	0.26	<0.47	8.56	<0.69		1.34					
MK	54.00.79?-5	Interparticle 2	93.16	0.89	<0.40	0.26	0.15	0.30	0.12	<0.47	2.51	<0.69		0.71					
MK	54.00.79?-6	Core 1	92.68	0.69	0.09	0.08	0.64	0.61	<0.65	<0.47	3.51	<0.69		0.49					
MK	54.00.79?-6	Core 2	88.63	1.00	1.23	0.35	0.60	0.67	<0.65	<0.47	5.15	<0.69		0.70		1.68			
MK	54.00.79?-6	Glaze 1	74.98	0.91	1.29	0.26	0.05	0.67	<0.65	<0.47	20.57	<0.69		2.31					
MK	54.00.79?-6	Glaze 2	73.74	0.85	1.82	0.22	0.03	0.84	<0.65	<0.47	19.71	<0.69		2.40		0.39			
MK	54.00.79?-6	Interparticle 1	69.81	1.09	1.44	0.16	10.42	2.65	<0.65	<0.47	14.60	<0.69		1.60					
MK	54.00.79?-6	Interparticle 2	69.43	0.62	0.68	<0.63	6.15	2.35	<0.65	<0.47	16.65	<0.69		2.08		2.05			

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	54.00.79?-7	Core 1	97.91	0.57	<0.40	<0.63	<0.83	0.42	<0.65	<0.47	0.51	<0.69		0.32					
MK	54.00.79?-7	Core 2	95.89	0.97	1.23	0.42	0.14	0.50	<0.65	<0.47	1.95	<0.69		0.78					
MK	54.00.79?-7	Glaze 1	79.52	0.84	0.88	0.26	0.87	0.96	<0.65	<0.47	8.62	<0.69		3.43		4.62			
MK	54.00.79?-7	Glaze 2	78.75	0.50	5.74	0.06	0.50	0.79	<0.65	<0.47	6.72	<0.69		2.62		4.31			
MK	54.00.79?-7	Interparticle 1	92.55	0.81	0.77	0.13	0.54	0.74	<0.65	<0.47	3.04	<0.69		1.02					
MK	54.00.79?-7	Interparticle 2	80.17	0.74	1.41	0.03	6.81	1.17	<0.65	<0.47	4.99	<0.69		1.31		3.36			
MK	54.00.79?-8	Core 1	84.15	1.02	1.30	0.16	6.66	1.59	<0.65	<0.47	4.54	<0.69		0.85					
MK	54.00.79?-8	Core 2	90.20	0.91	0.43	0.22	2.80	0.66	<0.65	<0.47	1.65	<0.69		0.45					
MK	54.00.79?-8	Glaze 1	68.87	0.65	6.38	0.17	12.09	2.12	<0.65	<0.47	5.96	<0.69		1.27		2.51			
MK	54.00.79?-8	Glaze 2	75.96	0.98	1.77	0.18	0.81	0.86	<0.65	<0.47	18.73	<0.69		1.74					
MK	54.00.79?-8	Interparticle 1	72.54	0.84	3.96	0.16	11.40	2.11	<0.65	<0.47	8.10	<0.69		1.47					

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	54.00.79?-8	Interparticle 2	88.39	1.08	0.70	0.30	0.50	0.66	<0.65	<0.47	4.58	<0.69		1.06		2.72			
MK	54.00.79?-9	Core 1	94.75	0.89	<0.40	0.24	0.32	0.35	<0.65	<0.47	0.91	<0.69		0.40					
MK	54.00.79?-9	Core 2	97.43	0.94	<0.40	0.30	0.57	0.28	<0.65	<0.47	0.67	<0.69		0.36					
MK	54.00.79?-9	Glaze 1	80.52	0.85	1.33	0.25	0.98	0.68	<0.65	<0.47	8.36	<0.69		2.37		4.66			
MK	54.00.79?-9	Glaze 2	79.23	0.91	1.59	0.27	0.42	0.56	<0.65	<0.47	11.37	<0.69		2.83		2.83			
MK	54.00.79?-9	Interparticle 1	85.72	0.90	0.49	0.21	4.93	0.85	<0.65	<0.47	3.57	<0.69		0.51					
MK	54.00.79?-9	Interparticle 2	88.19	0.86	0.71	0.26	0.76	0.88	<0.65	<0.47	3.96	<0.69		0.85		3.53			
MK	54.00.79?-10	Core 1	97.25	0.87	<0.40	0.20	0.04	0.29	<0.65	<0.47	0.51	<0.69		0.16					
MK	54.00.79?-10	Core 2	96.61	0.96	<0.40	0.31	0.01	0.29	<0.65	<0.47	0.67	<0.69		0.16					
MK	54.00.79?-10	Glaze 1	72.65	0.96	0.69	0.21	0.17	0.51	<0.65	<0.47	18.30	<0.69		3.53		2.98			
MK	54.00.79?-10	Glaze 2	86.38	0.87	0.36	0.20	0.14	0.50	<0.65	<0.47	8.35	<0.69		1.37		1.83			

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	54.00.79?-10	Interparticle 1	84.81	0.59	0.60	<0.63	4.69	0.96	<0.65	<0.47	7.21	<0.69		0.90					
MK	54.00.79?-10	Interparticle 2	80.70	0.82	0.47	<0.63	7.71	1.13	<0.65	<0.47	10.22	<0.69		1.24					
MK	54.00.79-1	Core 1	81.08	0.96	1.29	0.22	6.13	1.80	0.93	<0.47	8.38	<0.69							
MK	54.00.79-1	Core 2	82.17	0.88	0.71	0.06	7.62	1.32	0.84	<0.47	7.01	<0.69							
MK	54.00.79-1	Glaze 1	75.64	1.22	2.22	0.31	0.47	0.87	0.77	<0.47	14.77	<0.69				3.73			
MK	54.00.79-1	Glaze 2	80.16	1.04	2.37	0.36	0.36	0.66	0.05	<0.47	12.50	<0.69				2.49			
MK	54.00.79-1	Interparticle 1	78.85	1.14	1.75	0.35	0.44	0.83	<0.65	<0.47	16.57	<0.69				0.07			
MK	54.00.79-1	Interparticle 2	77.32	5.67	3.00	0.52	0.65	2.34	2.21	<0.47	4.21	<0.69				4.09			
MK	54.00.79-2	Core 1	90.96	0.84	0.85	0.19	3.58	0.67	0.04	<0.47	2.55	<0.69				0.33			
MK	54.00.79-2	Core 2	91.77	1.02	0.12	0.34	0.75	0.36	0.36	<0.47	4.95	<0.69		0.93					
MK	54.00.79-2	Glaze 1	73.57	0.97	6.16	0.32	0.41	0.98	0.50	<0.47	13.34	<0.69				3.76			

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	54.00.79-2	Glaze 2	81.63	0.96	0.73	0.31	0.14	0.60	<0.65	<0.47	11.32	<0.69		1.68		2.27			
MK	54.00.79-2	Interparticle 1	71.73	0.74	3.03	0.03	8.95	1.71	0.38	<0.47	8.91	<0.69		1.90		2.61			
MK	54.00.79-2	Interparticle 2	80.87	0.80	<0.40	0.12	0.55	0.56	0.29	<0.47	10.48	<0.69		2.49		3.28			
MK	54.00.79-3	Core 1	97.06	0.78	<0.40	0.11	0.01	0.32	0.09	<0.47	0.63	<0.69		0.08					
MK	54.00.79-3	Core 2	93.58	0.61	0.40	<0.63	1.26	0.51	0.07	<0.47	1.15	<0.69		0.52					
MK	54.00.79-3	Glaze 1	86.14	0.82	0.42	0.20	0.29	0.48	0.07	<0.47	6.98	<0.69		1.60		3.01			
MK	54.00.79-3	Glaze 2	74.79	0.97	4.58	0.32	0.41	0.97	0.43	<0.47	9.18	<0.69		2.77		5.59			
MK	54.00.79-3	Interparticle 1	73.16	0.90	0.89	0.20	0.06	0.87	0.14	<0.47	15.63	<0.69		3.40		4.75			
MK	54.00.79-3	Interparticle 2	70.48	0.81	5.50	0.24	10.93	2.27	0.74	<0.47	7.98	<0.69		2.63					
MK	54.00.79-4	Core 1	88.94	1.01	0.15	0.19	3.51	0.69	0.36	<0.47	3.59	<0.69		0.25					
MK	54.00.79-4	Core 2	87.10	0.98	1.30	0.21	5.01	0.97	0.75	<0.47	5.77	<0.69		0.45					

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	54.00.79-4	Glaze 1	69.71	1.20	1.14	0.12	3.09	2.09	0.71	<0.47	15.40	<0.69		1.53		5.02			
MK	54.00.79-4	Glaze 2	77.68	1.05	0.77	0.22	0.14	0.42	0.26	<0.47	16.24	<0.69		1.81		1.42			
MK	54.00.79-4	Interparticle 1	69.52	1.44	1.56	0.17	9.12	2.96	1.20	<0.47	15.06	<0.69		1.57					
MK	54.00.79-4	Interparticle 2	80.21	0.74	0.81	<0.63	0.12	0.52	0.17	<0.47	12.85	<0.69		1.62		2.95			
MK	54.00.79-5	Core 1	92.74	0.74	<0.40	<0.63	2.61	0.47	0.15	<0.47	3.02	<0.69		0.25		0.02			
MK	54.00.79-5	Core 2	93.15	0.90	0.06	0.18	0.14	0.46	0.06	<0.47	2.09	<0.69		0.32					
MK	54.00.79-5	Glaze 1	76.86	0.85	0.62	0.19	<0.83	0.24	<0.65	<0.47	16.77	<0.69		2.74		1.73			
MK	54.00.79-5	Glaze 2	77.23	0.94	0.79	0.13	0.09	0.37	0.47	<0.47	14.06	<0.69		2.93		2.98			
MK	54.00.79-5	Interparticle 1	80.23	1.61	1.93	0.26	1.29	1.23	1.63	<0.47	8.51	<0.69		1.16		2.18			
MK	54.00.79-5	Interparticle 2	74.72	0.70	0.92	0.01	0.26	0.74	0.14	<0.47	14.78	<0.69		3.34		4.39			
MK	54.00.79-6	Core 1	89.44	0.96	0.26	0.12	1.62	0.58	0.37	<0.47	5.32	<0.69		0.63					

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	54.00.79-6	Core 2	94.28	0.71	<0.40	0.09	0.66	0.28	0.17	<0.47	0.95	<0.69		0.05					
MK	54.00.79-6	Glaze 1	82.47	1.00	1.00	0.38	0.42	0.62	<0.65	<0.47	13.28	<0.69		2.30					
MK	54.00.79-6	Glaze 2	78.90	0.53	2.75	0.51	<0.83	0.30	<0.65	<0.47	10.57	<0.69		2.10		4.35			
MK	54.00.79-6	Interparticle 1	70.43	0.65	1.02	0.05	6.48	1.96	0.95	<0.47	15.24	<0.69		1.53		1.69			
MK	54.00.79-6	Interparticle 2	92.04	1.01	0.63	0.33	0.33	0.46	0.15	<0.47	6.14	<0.69		0.92					
MK	54.00.79-7	Core 1	97.06	0.69	<0.40	0.09	<0.83	0.36	0.04	<0.47	0.70	<0.69							
MK	54.00.79-7	Core 2	97.59	0.88	<0.40	0.29	0.11	0.30	0.19	<0.47	0.60	<0.69		0.22					
MK	54.00.79-7	Glaze 1	72.87	0.71	1.68	0.26	<0.83	0.56	0.10	<0.47	16.81	<0.69		3.00		4.00			
MK	54.00.79-7	Glaze 2	88.86	0.91	0.15	0.22	0.37	0.39	0.18	<0.47	7.08	<0.69		1.69					
MK	54.00.79-7	Interparticle 1	87.53	0.77	0.50	0.20	0.28	0.67	0.15	<0.47	5.74	<0.69		1.06		3.10			
MK	54.00.79-7	Interparticle 2	86.66	1.06	0.34	0.26	3.98	0.89	0.93	<0.47	2.86	<0.69		0.81					

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	54.00.79-8	Core 1	94.33	0.90	<0.40	0.26	0.13	0.39	<0.65	<0.47	0.76	<0.69		0.27					
MK	54.00.79-8	Core 2	97.87	0.89	<0.40	0.22	<0.83	0.23	0.15	<0.47	0.84	<0.69		0.25					
MK	54.00.79-8	Glaze 1	75.21	0.75	0.69	0.17	0.82	1.40	0.09	<0.47	19.31	<0.69		3.02					
MK	54.00.79-8	Glaze 2	58.16	0.87	1.58	0.20	0.17	1.05	0.59	<0.47	30.17	<0.69		2.44		4.77			
MK	54.00.79-8	Interparticle 1	80.93	0.99	1.60	0.18	6.91	1.32	1.07	<0.47	8.12	<0.69		1.10					
MK	54.00.79-8	Interparticle 2	96.17	0.84	<0.40	0.25	0.29	0.25	0.10	<0.47	0.39	<0.69		0.26					
MK	54.00.79-9	Core 1	85.53	0.88	0.21	0.09	5.56	1.13	0.83	<0.47	6.81	<0.69		0.78					
MK	54.00.79-9	Core 2	95.99	0.83	0.03	0.27	<0.83	0.40	<0.65	<0.47	0.72	<0.69		0.30					
MK	54.00.79-9	Glaze 1	78.67	0.85	0.85	0.21	<0.83	0.29	0.16	<0.47	14.83	<0.69		1.68		2.45			
MK	54.00.79-9	Glaze 2	63.23	0.70	3.05	0.04	0.01	0.46	0.65	<0.47	24.74	<0.69		2.91		4.21			
MK	54.00.79-9	Interparticle 1	88.88	1.06	0.53	0.38	0.31	0.38	<0.65	<0.47	7.00	<0.69		0.87					

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	54.00.79-9	Interparticle 2	92.67	0.86	0.35	0.24	0.20	0.33	0.22	<0.47	4.80	<0.69		0.56					
MK	54.00.79-10	Core 1	86.59	0.80	0.26	0.17	4.31	0.72	0.34	<0.47	5.50	<0.69		0.69		0.62			
MK	54.00.79-10	Core 2	74.93	0.84	1.29	0.15	9.03	1.51	0.31	<0.47	9.94	<0.69		1.21					
MK	54.00.79-10	Glaze 1	73.89	0.94	0.57	0.22	0.41	0.61	0.25	<0.47	22.38	<0.69		2.59					
MK	54.00.79-10	Glaze 2	83.38	0.95	0.40	0.22	0.21	0.51	0.14	<0.47	15.00	<0.69		1.55					
MK	54.00.79-10	Interparticle 1	83.31	0.85	0.32	0.20	1.07	0.74	0.05	<0.47	11.11	<0.69		1.73					
MK	54.00.79-10	Interparticle 2	85.92	0.65	0.45	0.02	5.83	1.20	0.17	<0.47	7.74	<0.69		0.80					
MK	9384-1	Core 1	83.68	1.03	0.52	0.27	1.70	1.72	9.04	<0.47	1.94	<0.69							
MK	9384-1	Core 2	97.27	0.84	<0.40	0.28	0.20	0.32	0.18	<0.47	0.64	<0.69							
MK	9384-1	Glaze 1	75.72	0.71	0.85	0.06	0.01	0.21	2.96	<0.47	18.73	0.05							
MK	9384-1	Glaze 2	77.66	0.73	0.36	0.12	0.10	0.17	2.89	<0.47	17.81	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	9384-1	Interparticle 1	84.70	0.81	0.32	0.07	4.38	1.37	4.59	<0.47	2.72	<0.69							
MK	9384-1	Interparticle 2	93.55	0.92	0.23	0.33	0.56	0.62	1.19	<0.47	1.53	0.05							
MK	9384-2	Core 1	98.86	0.60	<0.40	0.02	<0.83	0.35	0.08	<0.47	0.34	0.25							
MK	9384-2	Core 2	71.39	1.23	6.35	0.31	0.82	0.34	0.69	<0.47	0.30	19.20							
MK	9384-2	Glaze 1	62.73	1.38	3.97	0.48	15.25	2.55	1.03	<0.47	12.71	2.70							
MK	9384-2	Glaze 2	60.11	0.71	4.30	0.09	10.04	2.35	0.44	<0.47	16.45	5.07							
MK	9384-2	Interparticle 1	78.67	0.85	1.81	0.12	7.08	1.71	0.28	<0.47	3.78	7.06							
MK	9384-2	Interparticle 2	75.75	0.80	1.41	<0.63	7.61	1.34	<0.65	<0.47	5.21	6.03							
MK	9384-3	Core 1	92.09	0.83	0.11	0.20	1.71	0.53	0.26	<0.47	1.28	0.04							
MK	9384-3	Core 2	95.89	0.87	<0.40	0.22	0.34	0.25	0.10	<0.47	1.04	<0.69							
MK	9384-3	Glaze 1	60.05	2.52	12.71	0.34	11.64	2.88	0.90	<0.47	7.46	0.01							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	9384-3	Glaze 2	67.58	0.64	1.11	0.06	0.49	1.35	0.47	<0.47	28.36	0.05							
MK	9384-3	Interparticle 1	67.95	0.68	1.14	<0.63	6.79	3.25	0.06	<0.47	21.58	0.04							
MK	9384-3	Interparticle 2	95.49	0.90	<0.40	0.33	0.32	0.31	0.27	<0.47	0.64	<0.69							
MK	9384-4	Core 1	94.72	0.78	<0.40	0.22	0.15	0.34	0.43	<0.47	0.69	0.07							
MK	9384-4	Core 2	98.78	0.88	<0.40	0.21	0.11	0.37	0.32	<0.47	0.48	0.06							
MK	9384-4	Glaze 1	77.98	0.97	0.52	0.34	0.52	0.51	1.98	<0.47	15.69	<0.69							
MK	9384-4	Glaze 2	83.19	0.95	0.56	0.30	0.13	0.52	4.26	<0.47	11.19	0.01							
MK	9384-4	Interparticle 1	84.52	0.92	0.44	0.15	3.17	1.57	6.54	<0.47	1.58	<0.69							
MK	9384-4	Interparticle 2	84.51	1.01	0.06	0.15	3.76	1.52	7.10	<0.47	1.15	<0.69							
MK	9384-5	Core 1	97.05	0.92	<0.40	0.30	0.16	0.36	0.61	<0.47	0.63	<0.69							
MK	9384-5	Core 2	95.52	0.57	<0.40	<0.63	<0.83	0.36	0.26	<0.47	0.51	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	9384-5	Glaze 1	81.22	1.09	0.24	0.24	0.13	0.27	2.55	<0.47	12.30	0.04							
MK	9384-5	Glaze 2	75.98	0.73	0.97	0.49	<0.83	0.36	4.06	<0.47	17.05	0.17							
MK	9384-5	Interparticle 1	90.58	0.81	<0.40	0.09	0.61	0.65	3.50	<0.47	1.85	<0.69							
MK	9384-5	Interparticle 2	69.30	1.10	0.81	0.23	7.34	2.55	13.11	<0.47	3.89	0.06							
MK	9384-6	Core 1	88.17	1.05	0.11	0.28	1.83	1.74	1.23	<0.47	0.91	2.70							
MK	9384-6	Core 2	95.37	0.85	<0.40	0.29	<0.83	0.26	0.19	<0.47	0.49	<0.69							
MK	9384-6	Glaze 1	78.77	0.87	0.32	0.09	0.18	0.40	0.23	<0.47	14.25	2.25							
MK	9384-6	Glaze 2	74.32	1.27	3.31	0.33	0.21	1.08	1.12	<0.47	17.05	2.48							
MK	9384-6	Interparticle 1	66.32	1.22	1.03	0.22	7.63	6.22	4.35	<0.47	5.37	7.64							
MK	9384-6	Interparticle 2	76.29	0.61	1.20	0.08	0.11	0.96	0.62	<0.47	13.49	3.66							
MK	9384-7	Core 1	97.91	0.78	<0.40	0.23	0.09	0.30	0.13	<0.47	0.45	0.24							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	9384-7	Core 2	77.66	0.82	0.54	0.25	5.57	2.07	2.43	<0.47	1.25	8.66							
MK	9384-7	Glaze 1	73.11	0.53	0.70	<0.63	0.20	0.99	0.98	<0.47	16.34	4.84							
MK	9384-7	Glaze 2	62.50	0.72	1.69	0.12	12.41	3.32	0.50	<0.47	15.42	5.12							
MK	9384-7	Interparticle 1	62.49	1.16	1.36	0.22	7.54	3.91	4.81	<0.47	2.02	15.37							
MK	9384-7	Interparticle 2	63.77	0.69	2.02	0.21	12.03	3.57	1.04	<0.47	4.60	11.83							
MK	9384-8	Core 1	97.28	0.77	<0.40	0.24	0.09	0.32	0.16	<0.47	0.53	<0.69							
MK	9384-8	Core 2	86.45	1.53	0.30	0.32	0.74	1.12	2.68	<0.47	4.66	<0.69							
MK	9384-8	Glaze 1	75.09	0.94	1.55	0.31	0.07	0.33	0.42	<0.47	21.75	<0.69							
MK	9384-8	Glaze 2	77.82	0.63	0.20	0.11	0.37	0.53	<0.65	<0.47	20.86	0.09							
MK	9384-8	Interparticle 1	93.39	0.94	<0.40	0.19	0.75	0.48	<0.65	<0.47	1.48	<0.69							
MK	9384-8	Interparticle 2	76.35	0.65	2.24	0.22	0.74	1.09	0.16	<0.47	21.12	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
MK	9384-9	Core 1	93.20	0.80	<0.40	0.19	0.56	0.63	0.89	<0.47	1.21	<0.69							
MK	9384-9	Core 2	97.33	0.95	<0.40	0.25	0.30	0.28	0.17	<0.47	0.83	<0.69							
MK	9384-9	Glaze 1	63.14	0.67	6.10	0.05	14.19	3.63	1.05	<0.47	13.97	0.05							
MK	9384-9	Glaze 2	55.70	9.24	6.81	0.50	11.66	5.12	2.28	<0.47	9.52	<0.69							
MK	9384-9	Interparticle 1	95.09	0.80	<0.40	0.19	0.22	0.31	<0.65	<0.47	0.83	0.01							
MK	9384-9	Interparticle 2	71.87	1.01	1.99	0.17	0.63	1.84	6.41	<0.47	18.49	<0.69							
MK	9384-10	Core 1	63.79	<0.29	<0.40	32.59	<0.83	<0.42	5.27	<0.47	<0.85	<0.69							
MK	9384-10	Core 2	64.13	<0.29	<0.40	32.79	<0.83	<0.42	5.29	<0.47	<0.85	<0.69							
MK	9384-10	Glaze 1	58.66	0.77	1.13	11.22	14.65	2.60	2.73	<0.47	9.95	0.01							
MK	9384-10	Glaze 2	60.67	0.51	0.36	8.87	14.36	3.40	3.54	<0.47	7.15	<0.69							
NK	2344-1	Core 1	64.66	0.96	1.21	0.16	4.60	4.83	9.51	<0.47	1.67	12.42						2.35	

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2344-1	Core 2	95.58	0.95	<0.40	0.22	0.17	0.40	0.19	<0.47	0.52	0.09						1.69	
NK	2344-1	Glaze 1	64.36	0.74	2.14	0.04	6.16	4.29	2.40	<0.47	7.23	10.38						2.00	
NK	2344-1	Glaze 2	54.93	2.96	3.49	0.56	4.87	4.57	8.51	<0.47	10.46	8.04						2.92	
NK	2344-1	Interparticle 1	84.05	0.84	0.64	0.16	2.43	2.22	3.26	<0.47	1.90	4.11							
NK	2344-1	Interparticle 2	57.23	0.82	8.82	0.60	4.30	1.83	6.04	<0.47	2.52	18.54							
NK	2344-2	Core 1	91.87	0.86	<0.40	0.22	1.36	0.70	1.22	<0.47	1.01	1.60						1.68	
NK	2344-2	Core 2	94.04	0.85	<0.40	0.26	0.18	0.23	0.14	<0.47	0.51	0.10						1.41	
NK	2344-2	Glaze 1	57.96	0.65	3.99	0.12	7.08	4.49	3.71	<0.47	12.31	9.65						1.75	
NK	2344-2	Glaze 2	60.70	0.81	6.56	0.34	5.33	4.36	3.93	<0.47	9.31	6.82						2.71	
NK	2344-2	Interparticle 1	71.01	0.91	1.88	0.19	4.83	3.04	4.49	<0.47	3.86	8.45						1.98	
NK	2344-2	Interparticle 2	59.23	1.16	2.60	0.07	5.84	4.89	8.04	<0.47	5.68	11.40						2.21	

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2344-3	Core 1	54.93	0.79	17.69	0.11	<0.83	<0.42	0.40	<0.47	28.02	<0.69							
NK	2344-3	Core 2	57.39	0.97	19.10	0.05	0.06	0.05	0.39	<0.47	20.83	<0.69							
NK	2344-3	Glaze 1	55.54	1.57	18.72	0.25	0.65	0.54	1.41	<0.47	22.62	<0.69							
NK	2344-3	Glaze 2	52.12	2.53	14.63	0.24	1.17	1.23	3.21	<0.47	24.27	0.04							
NK	2344-3	Interparticle 1	48.75	1.37	35.45	0.88	0.53	0.25	2.36	<0.47	13.40	<0.69							
NK	2344-3	Interparticle 2	49.43	3.30	24.92	0.44	2.65	1.58	3.48	<0.47	14.62	0.20							
NK	2344-4	Core 1	48.12	0.73	27.39	0.07	<0.83	<0.42	1.41	<0.47	21.91	0.05							
NK	2344-4	Core 2	45.80	1.12	28.22	0.28	0.18	0.33	2.20	<0.47	21.30	<0.69							
NK	2344-4	Glaze 1	53.72	0.80	18.97	<0.63	0.02	<0.42	1.48	<0.47	26.94	0.11							
NK	2344-4	Glaze 2	50.08	0.96	24.37	0.25	0.05	<0.42	1.25	<0.47	25.55	<0.69							
NK	2344-4	Interparticle 1	54.17	0.98	18.44	0.29	0.17	0.05	2.15	<0.47	22.08	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2344-4	Interparticle 2	49.38	2.65	28.32	0.37	2.02	1.35	3.38	<0.47	11.49	<0.69							
NK	2344-5	Core 1	48.82	1.63	32.82	0.73	0.95	0.65	1.78	<0.47	9.66	<0.69							
NK	2344-5	Core 2	58.80	0.98	17.99	0.28	0.05	0.06	0.63	<0.47	23.33	<0.69							
NK	2344-5	Glaze 1	52.65	1.40	28.75	0.29	0.48	0.57	1.71	<0.47	15.00	0.09							
NK	2344-5	Glaze 2	46.41	1.99	38.34	0.44	1.18	0.82	2.15	<0.47	7.40	<0.69							
NK	2344-5	Interparticle 1	46.14	1.09	30.16	0.17	0.12	0.55	3.03	<0.47	18.07	0.01							
NK	2344-5	Interparticle 2	49.79	2.21	20.13	0.16	1.46	1.02	2.44	<0.47	20.14	<0.69							
NK	2344-6	Core 1	48.59	1.41	42.07	0.71	0.63	0.27	0.82	<0.47	3.44	<0.69							
NK	2344-6	Core 2	69.36	1.28	11.88	0.20	0.10	0.65	1.69	<0.47	17.63	<0.69							
NK	2344-6	Glaze 1	57.63	0.63	20.39	0.11	0.01	<0.42	0.21	<0.47	21.30	<0.69							
NK	2344-6	Glaze 2	53.96	0.98	30.14	0.39	<0.83	0.07	0.35	<0.47	16.83	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2344-6	Interparticle 1	59.39	1.50	25.23	0.43	0.50	0.27	0.80	<0.47	12.47	<0.69							
NK	2344-6	Interparticle 2	57.73	1.04	19.60	0.05	0.07	0.05	0.59	<0.47	21.33	<0.69							
NK	2344-7	Core 1	60.94	0.79	14.40	0.06	<0.83	0.01	0.17	<0.47	18.04	<0.69				5.58			
NK	2344-7	Core 2	52.77	1.32	25.23	0.32	0.49	0.43	1.39	<0.47	15.61	<0.69		0.36					
NK	2344-7	Glaze 1	42.12	0.97	13.82	0.31	0.28	0.18	0.39	<0.47	12.41	<0.69				29.51			
NK	2344-7	Glaze 2	46.28	24.31	10.79	0.78	4.02	0.36	12.08	<0.47	2.29	<0.69		0.60					
NK	2344-7	Interparticle 1	39.19	1.20	29.04	0.69	0.92	0.24	1.01	<0.47	3.43	<0.69		0.67		23.60			
NK	2344-7	Interparticle 2	56.87	1.22	22.29	0.37	0.34	0.19	0.74	<0.47	16.90	<0.69							
NK	2344-8	Core 1	44.12	0.76	21.22	0.16	0.02	0.10	1.12	<0.47	32.89	<0.69		0.31					
NK	2344-8	Core 2	50.07	1.39	36.12	0.38	0.66	0.46	1.27	<0.47	8.89	<0.69							
NK	2344-8	Glaze 1	44.80	0.84	22.64	0.10	<0.83	0.07	1.73	<0.47	30.23	<0.69		0.22					

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2344-8	Glaze 2	59.01	1.36	17.47	0.34	0.31	0.15	0.69	<0.47	23.67	<0.69							
NK	2344-8	Interparticle 1	24.45	0.57	27.69	<0.63	0.10	0.02	0.99	<0.47	43.26	<0.69		0.15					
NK	2344-8	Interparticle 2	52.40	1.49	18.32	0.40	0.60	0.29	0.63	<0.47	23.53	<0.69							
NK	2344-9	Core 1	56.46	1.18	16.35	0.25	<0.83	0.55	1.66	<0.47	25.35	<0.69		0.66					
NK	2344-9	Core 2	52.40	0.80	31.54	1.81	0.40	<0.42	1.27	<0.47	9.00	<0.69							
NK	2344-9	Glaze 1	65.87	3.19	13.06	0.88	0.96	0.59	1.58	<0.47	12.35	<0.69		1.24					
NK	2344-9	Glaze 2	57.42	1.44	20.22	0.35	0.18	0.15	0.82	<0.47	15.50	<0.69				3.93			
NK	2344-9	Interparticle 1	60.39	0.99	17.56	0.05	<0.83	<0.42	0.18	<0.47	19.44	<0.69				0.36			
NK	2344-9	Interparticle 2	55.61	1.28	29.58	0.35	0.39	0.29	0.23	<0.47	10.45	<0.69							
NK	2344-10	Core 1	47.52	1.14	30.55	0.10	0.27	0.27	1.19	<0.47	18.44	<0.69							
NK	2344-10	Core 2	46.35	1.28	25.57	0.35	0.45	0.59	1.43	<0.47	22.85	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2344-10	Glaze 1	51.37	1.06	34.37	0.62	0.01	0.29	0.77	<0.47	8.93	<0.69							
NK	2344-10	Glaze 2	52.44	1.08	21.23	0.32	0.47	0.30	1.06	<0.47	24.38	0.13							
NK	2344-10	Interparticle 1	52.78	0.59	19.90	0.17	<0.83	<0.42	0.15	<0.47	25.13	<0.69							
NK	2344-10	Interparticle 2	50.42	1.26	19.88	0.26	0.29	0.38	1.71	<0.47	24.43	0.14							
NK	2375-1	Core 1	85.72	1.09	0.14	0.35	0.95	0.27	0.81	<0.47	4.79	<0.69				5.86			
NK	2375-1	Core 2	85.08	1.01	0.12	0.44	0.17	0.14	0.55	<0.47	2.47	0.05				9.96			
NK	2375-1	Glaze 1	73.72	0.98	0.32	0.28	0.28	0.10	0.28	<0.47	8.26	0.02				15.76			
NK	2375-1	Glaze 2	74.17	0.70	0.24	0.19	0.14	0.14	0.11	<0.47	5.69	<0.69				18.62			
NK	2375-1	Interparticle 1	81.89	1.00	<0.40	0.30	0.28	0.18	0.08	<0.47	3.55	0.09				12.64			
NK	2375-1	Interparticle 2	88.27	1.10	<0.40	0.37	0.18	0.22	0.15	<0.47	2.01	0.07				7.63			
NK	2375-2	Core 1	96.15	0.81	<0.40	0.29	0.09	0.34	0.13	<0.47	0.44	0.02							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2375-2	Core 2	93.49	1.19	0.68	0.45	0.14	0.25	1.08	<0.47	2.74	<0.69							
NK	2375-2	Glaze 1	88.61	0.72	<0.40	0.13	<0.83	0.13	0.26	<0.47	8.83	0.08							
NK	2375-2	Glaze 2	80.29	0.68	0.92	0.16	0.08	0.27	<0.65	<0.47	15.39	0.04				2.17			
NK	2375-2	Interparticle 1	80.74	0.74	0.28	0.16	0.05	0.14	0.45	<0.47	14.89	0.03				2.53			
NK	2375-2	Interparticle 2	79.87	0.76	3.86	0.37	0.02	0.17	1.00	<0.47	11.61	<0.69				2.33			
NK	2375-3	Core 1	94.25	0.98	<0.40	0.37	0.19	0.27	0.07	<0.47	1.01	<0.69							
NK	2375-3	Core 2	96.22	0.98	<0.40	0.35	0.15	0.37	0.14	<0.47	1.06	0.02							
NK	2375-3	Glaze 1	94.19	1.07	<0.40	0.32	0.44	0.24	0.24	<0.47	2.67	0.08							
NK	2375-3	Glaze 2	92.91	1.47	0.09	0.34	0.08	0.30	0.23	<0.47	4.01	0.13							
NK	2375-3	Interparticle 1	92.93	1.22	<0.40	0.34	0.24	0.25	0.47	<0.47	2.89	<0.69							
NK	2375-3	Interparticle 2	93.78	0.96	<0.40	0.34	0.20	0.22	0.14	<0.47	2.43	0.05							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2375-4	Core 1	87.84	1.40	0.83	0.79	0.46	0.35	1.76	<0.47	3.87	0.15							
NK	2375-4	Core 2	93.78	1.47	0.19	0.52	0.22	0.43	1.87	<0.47	4.33	0.11							
NK	2375-4	Glaze 1	85.38	0.86	0.77	0.35	<0.83	0.18	0.20	<0.47	11.46	0.11							
NK	2375-4	Glaze 2	84.74	0.89	0.47	0.49	0.12	0.24	0.07	<0.47	15.65	0.07							
NK	2375-4	Interparticle 1	92.13	1.11	0.35	0.29	0.04	0.28	1.22	<0.47	3.32	0.09							
NK	2375-4	Interparticle 2	89.36	1.98	0.37	0.47	0.11	0.27	0.37	<0.47	9.87	0.07							
NK	2375-5	Core 1	97.44	0.94	<0.40	0.36	0.27	0.35	<0.65	<0.47	0.95	<0.69							
NK	2375-5	Core 2	94.22	1.07	<0.40	0.36	0.46	0.33	0.12	<0.47	1.00	0.04							
NK	2375-5	Glaze 1	73.42	0.99	5.09	0.27	1.76	1.63	0.60	<0.47	7.38	0.05				8.82			
NK	2375-5	Glaze 2	72.84	1.05	3.64	0.37	0.16	0.38	0.50	<0.47	8.51	0.02				12.53			
NK	2375-5	Interparticle 1	75.75	1.19	4.64	0.33	0.99	0.91	1.38	<0.47	5.02	<0.69				9.80			

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2375-5	Interparticle 2	94.27	0.65	0.06	0.15	0.12	0.30	0.28	<0.47	3.25	<0.69							
NK	2375-6	Core 1	91.47	0.75	<0.40	0.19	<0.83	0.36	0.45	<0.47	6.25	<0.69							
NK	2375-6	Core 2	96.49	0.94	<0.40	0.28	<0.83	0.25	0.05	<0.47	1.31	<0.69							
NK	2375-6	Glaze 1	75.89	0.92	0.31	0.27	0.28	0.24	0.42	<0.47	20.70	0.18							
NK	2375-6	Glaze 2	83.17	1.13	2.36	0.19	<0.83	0.23	0.31	<0.47	14.60	<0.69							
NK	2375-6	Interparticle 1	79.75	1.88	1.01	0.45	0.09	0.56	3.74	<0.47	14.56	0.05							
NK	2375-6	Interparticle 2	80.60	1.08	1.05	0.30	<0.83	0.21	0.16	<0.47	14.54	<0.69							
NK	2375-7	Core 1	98.03	0.94	<0.40	0.26	0.03	0.32	0.46	<0.47	1.24	0.03							
NK	2375-7	Core 2	98.26	0.80	<0.40	0.17	0.04	0.30	0.23	<0.47	0.73	0.11							
NK	2375-7	Glaze 1	80.57	0.99	1.76	0.31	0.07	0.26	0.35	<0.47	13.34	<0.69							
NK	2375-7	Glaze 2	80.86	0.93	0.28	0.26	0.08	0.19	0.10	<0.47	16.77	<0.69				0.53			

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2375-7	Interparticle 1	87.84	1.07	0.52	0.45	0.04	0.27	0.83	<0.47	6.82	<0.69							
NK	2375-7	Interparticle 2	87.04	1.32	0.25	0.26	0.07	0.20	1.11	<0.47	8.01	<0.69							
NK	2375-8	Core 1	92.16	1.04	0.03	0.22	<0.83	0.27	0.78	<0.47	3.13	<0.69							
NK	2375-8	Core 2	93.24	1.01	<0.40	0.31	0.22	0.29	0.32	<0.47	3.01	0.11							
NK	2375-8	Glaze 1	76.89	2.38	3.85	0.67	0.25	0.68	3.72	<0.47	12.91	0.15							
NK	2375-8	Glaze 2	78.86	0.87	0.46	0.30	0.09	0.22	0.42	<0.47	14.79	<0.69				4.01			
NK	2375-8	Interparticle 1	90.66	1.23	0.34	0.39	0.06	0.28	1.17	<0.47	8.66	0.05							
NK	2375-8	Interparticle 2	82.80	0.95	0.21	0.29	<0.83	0.16	0.28	<0.47	12.88	<0.69							
NK	2375-9	Core 1	80.75	0.74	0.37	0.08	<0.83	0.15	0.31	<0.47	16.78	<0.69				0.82			
NK	2375-9	Core 2	83.60	1.41	0.43	0.35	0.17	0.36	3.42	<0.47	7.95	0.12				2.19			
NK	2375-9	Glaze 1	79.29	0.51	0.09	<0.63	<0.83	0.19	0.06	<0.47	20.13	0.01							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2375-9	Glaze 2	75.93	1.22	0.12	0.22	<0.83	0.23	0.14	<0.47	20.57	0.04							
NK	2375-9	Interparticle 1	78.31	0.51	<0.40	0.01	<0.83	0.20	0.28	<0.47	20.45	<0.69							
NK	2375-9	Interparticle 2	90.92	0.94	<0.40	0.24	0.14	0.30	0.23	<0.47	8.39	0.02							
NK	2375-10	Core 1	84.58	1.62	0.49	0.56	0.54	0.75	8.10	<0.47	3.90	0.11							
NK	2375-10	Core 2	93.86	1.09	0.21	0.18	0.47	0.41	3.31	<0.47	0.98	0.12							
NK	2375-10	Glaze 1	70.43	12.09	1.81	0.04	2.91	2.29	1.63	<0.47	5.97	<0.69							
NK	2375-10	Glaze 2	80.63	1.14	0.40	0.33	0.64	0.21	0.84	<0.47	17.76	0.05							
NK	2375-10	Interparticle 1	86.96	1.11	0.21	0.34	0.10	0.33	2.83	<0.47	6.49	0.09							
NK	2375-10	Interparticle 2	86.37	1.26	0.33	0.36	0.32	0.31	4.31	<0.47	5.59	<0.69							
NK	2377-1	Core 1	95.74	1.00	<0.40	0.32	0.09	0.27	0.21	<0.47	0.39	<0.69	0.20	0.29					
NK	2377-1	Core 2	98.07	0.72	<0.40	0.13	<0.83	0.28	0.13	<0.47	0.61	0.05	0.11						

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2377-1	Glaze 1	49.01	6.90	2.29	11.01	0.44	0.63	6.50	<0.47	22.35	0.03		1.51					
NK	2377-1	Glaze 2	79.90	1.95	0.48	2.87	0.57	0.27	0.16	<0.47	10.18	<0.69	0.29	1.47					
NK	2377-1	Interparticle 1	76.31	1.46	0.53	1.27	0.42	0.24	0.45	<0.47	6.21	<0.69	0.22	11.78					
NK	2377-1	Interparticle 2	92.84	1.13	0.05	0.26	0.19	0.33	1.35	<0.47	1.01	0.07		0.79					
NK	2377-2	Core 1	96.77	0.57	<0.40	<0.63	<0.83	0.26	0.64	<0.47	0.17	0.02		0.22					
NK	2377-2	Core 2	95.78	0.75	<0.40	0.24	<0.83	0.21	0.31	<0.47	0.57	<0.69	0.10						
NK	2377-2	Glaze 1	62.28	1.50	1.52	1.10	0.95	0.59	10.09	<0.47	14.40	0.12	0.61	3.95					
NK	2377-2	Glaze 2	69.31	1.39	0.76	0.46	0.33	0.45	8.30	<0.47	16.77	0.06	0.54	1.40					
NK	2377-2	Interparticle 1	82.77	0.87	0.35	0.48	0.53	0.18	10.52	<0.47	1.59	0.05		1.11	1.55				
NK	2377-2	Interparticle 2	90.60	1.13	<0.40	0.38	1.27	<0.42	7.16	<0.47	0.46	0.08							
NK	2377-3	Core 1	98.23	0.72	<0.40	0.18	<0.83	0.36	0.19	<0.47	0.51	0.04							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2377-3	Core 2	75.02	0.97	1.07	0.16	6.68	3.08	12.40	<0.47	2.84	0.22							
NK	2377-3	Glaze 1	90.44	0.61	0.16	0.03	0.06	0.50	1.88	<0.47	3.54	<0.69							
NK	2377-3	Glaze 2	82.33	0.43	0.67	1.26	<0.83	0.59	10.78	<0.47	4.07	0.09							
NK	2377-3	Interparticle 1	86.74	1.08	0.36	0.28	0.54	0.98	8.35	<0.47	4.31	0.05							
NK	2377-3	Interparticle 2	77.78	0.77	0.69	0.07	2.32	1.64	12.80	<0.47	4.43	0.15							
NK	2377-4	Core 1	91.22	1.12	1.49	0.40	0.49	0.28	6.65	<0.47	0.65	0.01							
NK	2377-4	Core 2	93.18	1.03	0.01	0.19	0.23	0.45	1.89	<0.47	0.53	0.05		0.28					
NK	2377-4	Glaze 1	60.95	3.11	2.17	5.39	<0.83	0.24	14.27	<0.47	9.81	0.21		2.82					
NK	2377-4	Glaze 2	53.80	7.67	1.34	4.62	1.19	0.49	13.84	<0.47	8.50	<0.69		9.02					
NK	2377-4	Interparticle 1	83.35	1.99	0.11	2.96	0.71	0.44	7.30	<0.47	2.60	0.08		0.25					
NK	2377-4	Interparticle 2	84.17	1.02	1.18	0.24	0.48	0.28	11.80	<0.47	1.35	0.04		0.21					

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2377-5	Core 1	72.45	22.14	0.08	0.13	0.45	0.11	0.13	<0.47	1.08	<0.69		2.14					
NK	2377-5	Core 2	37.54	55.94	0.48	0.75	1.1	0.07	0.02	<0.47	2.35	0.03		4.52					
NK	2377-5	Glaze 1	94.40	1.45	<0.40	0.10	0.99	0.52	0.16	<0.47	3.14	<0.69		0.31					
NK	2377-5	Glaze 2	91.33	3.13	<0.40	0.78	0.08	0.30	0.40	<0.47	3.60	<0.69		1.27					
NK	2377-5	Interparticle 1	88.55	6.45	<0.40	0.16	0.22	0.08	<0.65	<0.47	1.34	<0.69							
NK	2377-5	Interparticle 2	91.85	2.93	<0.40	0.46	0.30	0.51	0.71	<0.47	3.49	<0.69		0.91					
NK	2380-1	Core 1	95.51	0.82	<0.40	0.20	0.05	0.26	0.23	<0.47	0.73	<0.69		0.04					
NK	2380-1	Core 2	94.62	1.17	0.35	0.40	0.07	0.31	0.29	<0.47	5.43	<0.69		0.13					
NK	2380-1	Glaze 1	76.27	0.51	1.36	<0.63	<0.83	0.20	1.12	<0.47	16.47	<0.69		0.16		3.90			
NK	2380-1	Glaze 2	84.50	1.12	0.42	0.37	0.22	0.19	0.91	<0.47	10.64	<0.69							
NK	2380-1	Interparticle 1	86.77	0.89	0.48	0.02	0.05	0.25	2.19	<0.47	9.76	<0.69						1.74	

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2380-1	Interparticle 2	93.93	1.04	0.41	0.35	<0.83	0.22	0.46	<0.47	4.78	<0.69		0.07					
NK	2380-2	Core 1	77.41	<0.29	0.61	0.34	6.88	3.32	<0.65	<0.47	2.07	7.96				1.40			
NK	2380-2	Core 2	93.97	<0.29	0.04	0.35	0.19	0.18	<0.65	<0.47	3.44	1.08							
NK	2380-2	Glaze 1	80.83	<0.29	0.25	0.25	0.10	0.19	<0.65	<0.47	11.48	2.29				4.61			
NK	2380-2	Glaze 2	77.46	<0.29	1.64	0.27	0.17	0.24	<0.65	<0.47	18.03	3.29							
NK	2380-2	Interparticle 1	83.63	<0.29	0.48	0.29	0.47	0.41	<0.65	<0.47	5.97	5.82				2.93			
NK	2380-2	Interparticle 2	89.03	<0.29	0.03	0.23	2.50	1.07	<0.65	<0.47	1.17	3.62							
NK	2380-3	Core 1	62.64	1.23	0.21	<0.63	7.91	4.23	<0.65	<0.47	5.97	13.22				2.07		2.51	
NK	2380-3	Core 2	68.12	0.99	0.32	0.16	11.10	3.32	<0.65	<0.47	5.62	11.48							
NK	2380-3	Glaze 1	60.93	0.75	2.90	<0.63	9.71	3.45	<0.65	<0.47	21.54	1.42						1.47	
NK	2380-3	Glaze 2	67.52	0.80	0.52	0.23	0.15	0.33	<0.65	<0.47	29.53	2.70							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2380-3	Interparticle 1	67.80	0.86	2.48	<0.63	5.89	2.86	<0.65	<0.47	16.77	1.06						1.78	
NK	2380-3	Interparticle 2	71.86	0.79	0.44	0.12	0.14	0.24	<0.65	<0.47	24.32	2.79							
NK	2380-4	Core 1	65.81	1.11	1.24	0.12	8.71	4.14	<0.65	<0.47	10.22	7.80				0.87			
NK	2380-4	Core 2	63.51	1.06	2.39	0.07	11.39	3.85	<0.65	<0.47	6.80	9.54				1.39			
NK	2380-4	Glaze 1	67.76	0.84	1.03	0.25	0.14	0.18	<0.65	<0.47	21.77	3.86				4.17			
NK	2380-4	Glaze 2	60.17	0.81	3.39	<0.63	11.54	3.70	<0.65	<0.47	17.00	3.35				0.04			
NK	2380-4	Interparticle 1	66.25	2.30	0.66	0.28	12.56	4.30	<0.65	<0.47	11.63	2.92							
NK	2380-4	Interparticle 2	62.52	0.84	4.08	0.13	12.16	3.97	<0.65	<0.47	15.53	3.49							
NK	2380-5	Core 1	75.10	1.53	0.55	0.22	0.76	0.82	4.92	<0.47	14.93	0.26				0.40			
NK	2380-5	Core 2	84.45	0.93	0.30	0.21	4.17	1.38	1.16	<0.47	6.28	0.04				1.07			
NK	2380-5	Glaze 1	74.65	0.77	1.92	0.57	0.39	0.33	<0.65	<0.47	23.77	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2380-5	Glaze 2	67.11	1.52	2.09	0.23	0.52	2.63	4.87	<0.47	21.26	0.80							
NK	2380-5	Interparticle 1	73.86	0.93	0.21	0.26	0.24	0.09	<0.65	<0.47	22.38	<0.69				2.03			
NK	2380-5	Interparticle 2	61.89	0.88	2.03	0.11	12.16	3.68	2.76	<0.47	16.21	0.72							
NK	2380-6	Core 1	95.88	0.60	<0.40	0.17	0.05	0.33	<0.65	<0.47	0.78	<0.69							
NK	2380-6	Core 2	90.52	0.91	<0.40	0.22	2.25	0.79	<0.65	<0.47	2.63	<0.69							
NK	2380-6	Glaze 1	82.85	1.03	0.19	0.11	0.06	0.11	<0.65	<0.47	17.69	<0.69							
NK	2380-6	Glaze 2	75.04	0.95	0.97	0.27	0.10	0.16	<0.65	<0.47	25.17	<0.69							
NK	2380-6	Interparticle 1	82.10	0.86	0.92	<0.63	0.13	0.30	<0.65	<0.47	<0.85	<0.69							
NK	2380-6	Interparticle 2	75.68	0.52	1.10	0.40	<0.83	0.29	<0.65	<0.47	21.50	<0.69				0.51			
NK	2380-7	Core 1	91.73	0.89	0.18	0.22	2.97	0.98	<0.65	<0.47	2.73	<0.69				0.30			
NK	2380-7	Core 2	95.40	0.92	0.09	0.26	2.53	0.84	<0.65	<0.47	2.88	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2380-7	Glaze 1	70.26	0.84	0.62	0.18	0.58	0.41	<0.65	<0.47	26.91	<0.69							
NK	2380-7	Glaze 2	69.93	0.66	2.07	0.03	1.10	0.43	<0.65	<0.47	23.76	<0.69				2.02			
NK	2380-7	Interparticle 1	73.53	1.07	0.83	0.22	1.72	0.53	0.85	<0.47	18.13	<0.69				3.13			
NK	2380-7	Interparticle 2	63.71	0.67	1.95	0.16	9.15	3.88	<0.65	<0.47	17.33	<0.69				3.14			
NK	2380-8	Core 1	93.25	0.90	<0.40	0.28	<0.83	0.27	<0.65	<0.47	2.92	<0.69							
NK	2380-8	Core 2	82.32	1.88	0.57	0.49	0.72	0.63	1.74	<0.47	8.57	<0.69				3.08			
NK	2380-8	Glaze 1	74.14	0.90	0.41	0.27	0.12	0.13	<0.65	<0.47	22.83	<0.69				1.22			
NK	2380-8	Glaze 2	78.37	1.34	0.99	0.24	0.13	0.42	1.21	<0.47	19.32	<0.69							
NK	2380-8	Interparticle 1	84.89	1.17	0.13	0.39	0.12	0.18	<0.65	<0.47	14.12	<0.69							
NK	2380-8	Interparticle 2	67.91	1.64	0.90	0.24	11.33	3.27	2.45	<0.47	11.80	<0.69				0.46			
NK	2380-9	Core 1	81.01	0.90	0.46	0.05	6.39	2.21	0.89	<0.47	8.16	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2380-9	Core 2	62.46	0.98	4.37	0.09	13.16	3.84	0.46	<0.47	15.34	<0.69							
NK	2380-9	Glaze 1	71.51	0.87	2.29	0.19	0.35	0.36	0.28	<0.47	25.72	<0.69							
NK	2380-9	Glaze 2	71.57	0.90	1.41	0.27	0.27	0.14	<0.65	<0.47	28.14	<0.69							
NK	2380-9	Interparticle 1	84.39	0.94	0.41	0.05	6.55	1.94	1.01	<0.47	7.62	<0.69							
NK	2380-9	Interparticle 2	59.43	1.27	4.26	<0.63	13.51	3.62	0.63	<0.47	17.60	<0.69							
NK	2380-10	Core 1	94.34	0.96	0.07	0.29	0.01	0.23	<0.65	<0.47	2.91	<0.69							
NK	2380-10	Core 2	94.61	1.03	<0.40	0.30	0.11	0.31	<0.65	<0.47	5.00	<0.69							
NK	2380-10	Glaze 1	72.76	0.82	2.71	0.25	0.25	0.27	0.45	<0.47	23.16	<0.69							
NK	2380-10	Glaze 2	69.57	0.64	0.24	<0.63	<0.83	0.13	<0.65	<0.47	27.65	<0.69					0.62		
NK	2380-10	Interparticle 1	74.48	0.84	3.62	0.14	0.11	0.20	<0.65	<0.47	22.07	<0.69							
NK	2380-10	Interparticle 2	81.18	0.63	0.22	0.05	<0.83	0.17	<0.65	<0.47	14.55	<0.69				3.20			

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2384-1	Core 1	73.91	0.82	1.27	<0.63	6.73	2.76	<0.65	<0.47	8.97	2.07				3.46			
NK	2384-1	Core 2	69.02	0.97	1.92	<0.63	11.07	3.82	<0.65	<0.47	10.21	4.00						1.83	
NK	2384-1	Glaze 1	45.49	0.60	6.71	<0.63	1.01	2.42	<0.65	<0.47	15.37	<0.69				26.58		1.82	
NK	2384-1	Glaze 2	68.75	1.02	1.92	<0.63	10.18	4.60	<0.65	<0.47	9.65	4.56							
NK	2384-1	Interparticle 1	45.15	0.60	2.18	<0.63	1.89	4.93	1.54	<0.47	15.14	3.73				18.72		6.12	
NK	2384-1	Interparticle 2	70.70	1.17	1.49	<0.63	15.42	3.42	<0.65	<0.47	7.01	3.20							
NK	2384-2	Core 1	73.84	0.86	0.45	<0.63	3.99	1.14	3.17	<0.47	3.69	<0.69				3.95	8.90		
NK	2384-2	Core 2	66.34	0.84	1.70	<0.63	0.36	0.49	0.94	<0.47	3.72	<0.69				6.99	18.62		
NK	2384-2	Glaze 1	61.24	0.58	0.64	<0.63	<0.83	0.30	<0.65	<0.47	10.89	<0.69				12.47	13.89		
NK	2384-2	Glaze 2	65.24	0.73	0.66	<0.63	0.10	0.36	0.10	<0.47	11.99	<0.69					23.14		
NK	2384-2	Interparticle 1	24.27	0.51	1.43	<0.63	6.74	0.90	6.13	<0.47	3.08	<0.69					42.97		13.97

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2384-2	Interparticle 2	63.21	0.77	0.92	<0.63	0.05	0.08	0.32	<0.47	11.11	<0.69				2.49	21.05		
NK	2384-3	Core 1	84.48	0.65	<0.40	<0.63	2.92	0.72	3.63	<0.47	2.60	<0.69					4.49	1.68	
NK	2384-3	Core 2	82.08	0.84	<0.40	<0.63	3.38	0.73	<0.65	<0.47	2.00	<0.69					6.55	1.95	
NK	2384-3	Glaze 1	73.33	<0.29	2.77	<0.63	0.26	<0.42	<0.65	<0.47	7.39	<0.69		8.10		8.15			
NK	2384-3	Glaze 2	64.82	0.87	1.50	<0.63	<0.83	0.12	0.96	<0.47	10.33	<0.69				3.02	17.48	0.90	
NK	2384-3	Interparticle 1	63.38	0.55	0.65	<0.63	6.79	0.67	4.38	<0.47	3.60	<0.69				0.62	14.67		4.69
NK	2384-3	Interparticle 2	70.87	0.90	<0.40	<0.63	8.05	1.48	2.48	<0.47	5.45	<0.69					12.34		
NK	2384-4	Core 1	52.90	3.09	1.97	<0.63	2.79	1.82	35.45	<0.47	<0.85	<0.69		0.88					
NK	2384-4	Core 2	82.45	1.36	0.74	<0.63	2.01	0.76	6.28	<0.47	<0.85	<0.69		0.91		3.63		1.87	
NK	2384-4	Glaze 1	60.75	2.29	2.97	<0.63	11.53	2.34	15.65	<0.47	<0.85	<0.69		1.78		2.70			
NK	2384-4	Glaze 2	69.71	3.77	5.15	<0.63	1.04	1.57	13.90	<0.47	<0.85	<0.69		1.85		3.02			

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2384-4	Interparticle 1	64.54	3.03	1.65	<0.63	6.72	1.84	23.77	<0.47	<0.85	<0.69						1.25	
NK	2384-4	Interparticle 2	82.54	1.80	1.38	<0.63	4.56	1.19	7.57	<0.47	<0.85	<0.69				0.95			
NK	2384-5	Core 1	89.15	0.90	<0.40	<0.63	2.10	0.79	1.60	<0.47	<0.85	<0.69				1.24	4.22		
NK	2384-5	Core 2	84.72	1.30	0.12	<0.63	1.32	1.24	3.64	<0.47	<0.85	<0.69					5.92		
NK	2384-5	Glaze 1	59.55	0.87	3.06	<0.63	0.10	0.27	<0.65	<0.47	1.70	<0.69				4.79	29.65		
NK	2384-5	Glaze 2	67.03	1.38	1.06	<0.63	0.44	1.51	2.84	<0.47	1.07	<0.69					25.08		
NK	2384-5	Interparticle 1	58.57	0.75	0.65	<0.63	4.55	2.09	4.06	<0.47	<0.85	<0.69					28.19		
NK	2384-5	Interparticle 2	69.11	0.86	0.67	<0.63	4.97	2.01	5.95	<0.47	0.91	<0.69					15.72		
NK	2384-6	Core 1	96.87	0.87	<0.40	<0.63	<0.83	<0.42	<0.65	<0.47	<0.85	<0.69						1.80	
NK	2384-6	Core 2	95.21	0.99	<0.40	<0.63	<0.83	<0.42	<0.65	<0.47	<0.85	<0.69						2.04	
NK	2384-6	Glaze 1	81.56	1.11	8.77	0.39	0.57	0.85	0.39	<0.47	0.82	<0.69				5.54			

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2384-6	Glaze 2	89.41	0.97	0.22	<0.63	0.90	0.50	<0.65	<0.47	1.34	<0.69		0.73		5.94			
NK	2384-6	Interparticle 1	81.53	3.53	6.46	1.16	1.05	1.62	2.97	<0.47	<0.85	<0.69				1.68			
NK	2384-6	Interparticle 2	96.97	1.01	<0.40	<0.63	0.24	0.24	<0.65	<0.47	<0.85	<0.69						1.42	
NK	2384-7	Core 1	77.43	<0.29	2.00	<0.63	3.54	2.27	5.24	<0.47	<0.85	8.15						2.19	
NK	2384-7	Core 2	84.69	0.95	0.60	<0.63	3.92	1.15	2.00	<0.47	<0.85	3.46						1.59	
NK	2384-7	Glaze 1	77.54	0.97	3.09	<0.63	<0.83	<0.42	<0.65	<0.47	7.93	4.56				5.91			
NK	2384-7	Glaze 2	75.83	<0.29	4.09	<0.63	0.02	0.45	<0.65	<0.47	10.22	5.53				3.87			
NK	2384-7	Interparticle 1	65.07	1.08	3.24	<0.63	7.48	3.24	6.45	<0.47	1.73	10.35						2.16	
NK	2384-7	Interparticle 2	78.06	<0.29	4.42	<0.63	0.18	0.65	<0.65	<0.47	8.39	6.35				1.96			
NK	2384-8	Core 1	78.98	0.80	0.51	<0.63	0.09	0.61	5.87	<0.47	8.34	<0.69						1.87	
NK	2384-8	Core 2	66.22	1.37	3.53	<0.63	1.37	1.92	9.97	<0.47	14.77	<0.69				0.85			

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2384-8	Glaze 1	69.88	0.67	5.93	<0.63	0.09	1.72	1.20	<0.47	16.13	<0.69				4.39			
NK	2384-8	Glaze 2	75.89	0.88	0.74	<0.63	0.16	0.34	<0.65	<0.47	24.69	<0.69							
NK	2384-8	Interparticle 1	87.77	1.08	0.23	<0.63	4.01	1.32	0.22	<0.47	6.19	<0.69							
NK	2384-8	Interparticle 2	75.85	0.98	0.99	<0.63	0.04	0.36	<0.65	<0.47	22.71	<0.69							
NK	2384-9	Core 1	43.99	0.74	30.65	<0.63	0.20	0.09	1.06	<0.47	20.40	<0.69							
NK	2384-9	Core 2	49.57	1.61	27.04	<0.63	1.41	0.42	0.92	<0.47	19.03	<0.69							
NK	2384-9	Glaze 1	53.29	1.45	14.53	<0.63	0.27	0.36	<0.65	<0.47	24.02	<0.69				6.08			
NK	2384-9	Glaze 2	52.23	1.10	22.62	<0.63	0.03	0.31	0.60	<0.47	23.52	<0.69							
NK	2384-9	Interparticle 1	56.64	1.31	18.13	<0.63	0.62	0.33	1.85	<0.47	20.05	<0.69							
NK	2384-9	Interparticle 2	51.63	1.06	21.06	<0.63	<0.83	0.46	1.29	<0.47	25.24	<0.69							
NK	2384-10	Core 1	91.04	1.00	<0.40	0.21	2.00	0.54	<0.65	<0.47	2.80	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2384-10	Core 2	91.48	1.07	0.27	0.24	1.19	0.68	<0.65	<0.47	2.83	<0.69							
NK	2384-10	Glaze 1	81.05	0.95	0.18	<0.63	0.13	0.23	0.15	<0.47	18.26	<0.69							
NK	2384-10	Glaze 2	74.51	1.07	5.20	0.30	0.13	0.15	<0.65	<0.47	20.07	<0.69							
NK	2384-10	Interparticle 1	85.56	0.90	0.46	0.17	<0.83	0.31	<0.65	<0.47	13.89	<0.69							
NK	2384-10	Interparticle 2	88.27	1.03	0.30	0.32	0.40	0.66	<0.65	<0.47	7.42	<0.69				1.61			
NK	2389-1	Core 1	78.21	3.49	<0.40	0.22	0.98	2.35	9.79	<0.47	<0.85	<0.69						2.46	
NK	2389-1	Core 2	77.11	4.24	0.10	0.29	0.95	3.22	12.28	<0.47	<0.85	<0.69						2.38	
NK	2389-1	Glaze 1	69.06	4.09	1.34	0.38	1.60	1.76	11.39	<0.47	<0.85	<0.69				8.95		1.43	
NK	2389-1	Glaze 2	72.78	3.95	0.39	0.28	1.20	2.47	15.57	<0.47	<0.85	<0.69				1.16		2.19	
NK	2389-1	Interparticle 1	67.12	5.18	4.69	5.73	4.63	5.79	5.66	<0.47	<0.85	<0.69						3.18	
NK	2389-1	Interparticle 2	68.29	4.91	<0.40	0.08	1.22	4.05	18.03	<0.47	<0.85	<0.69				1.90		1.51	

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2389-2	Core 1	95.27	0.76	<0.40	<0.63	<0.83	0.31	0.79	<0.47	<0.85	<0.69						1.70	
NK	2389-2	Core 2	91.69	1.34	<0.40	<0.63	1.21	0.74	3.08	<0.47	<0.85	<0.69						1.92	
NK	2389-2	Glaze 1	75.77	3.87	3.46	0.89	0.53	1.44	14.56	<0.47	<0.85	<0.69						1.59	
NK	2389-2	Glaze 2	69.95	3.55	0.37	<0.63	3.44	2.34	18.61	<0.47	<0.85	<0.69							
NK	2389-2	Interparticle 1	71.61	2.93	<0.40	<0.63	5.47	2.13	17.18	<0.47	<0.85	<0.69						3.58	
NK	2389-2	Interparticle 2	67.74	2.83	1.85	<0.63	10.26	2.45	12.07	<0.47	<0.85	<0.69				2.80			
NK	2389-3	Core 1	73.34	2.90	1.19	<0.63	0.76	1.36	21.25	<0.47	<0.85	<0.69							
NK	2389-3	Core 2	95.08	0.92	<0.40	<0.63	0.05	0.34	0.67	<0.47	<0.85	<0.69							
NK	2389-3	Glaze 1	77.15	3.45	1.58	<0.63	0.49	1.57	13.80	<0.47	<0.85	<0.69				0.56		1.40	
NK	2389-3	Glaze 2	78.62	4.00	0.28	<0.63	0.41	1.98	14.95	<0.47	<0.85	<0.69							
NK	2389-3	Interparticle 1	66.84	3.25	0.79	<0.63	1.23	1.42	24.04	<0.47	<0.85	<0.69				1.09		1.33	

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2389-3	Interparticle 2	86.65	1.84	0.05	<0.63	0.84	1.51	7.93	<0.47	<0.85	<0.69							
NK	2389-4	Core 1	93.49	0.95	<0.40	<0.63	0.06	0.36	2.93	<0.47	<0.85	<0.69							
NK	2389-4	Core 2	81.39	2.23	0.84	<0.63	1.41	0.70	11.31	<0.47	<0.85	<0.69							
NK	2389-4	Glaze 1	76.96	2.86	0.84	<0.63	0.43	2.08	14.02	<0.47	<0.85	<0.69				2.82			
NK	2389-4	Glaze 2	75.79	3.16	1.66	<0.63	0.45	2.23	18.44	<0.47	<0.85	<0.69							
NK	2389-4	Interparticle 1	76.05	2.91	0.63	<0.63	0.70	2.55	16.45	<0.47	<0.85	<0.69				0.71			
NK	2389-4	Interparticle 2	77.57	1.69	0.48	<0.63	1.08	0.64	17.30	<0.47	<0.85	<0.69							
NK	2389-5	Core 1	99.10	1.17	<0.40	<0.63	0.39	0.34	1.60	<0.47	<0.85	<0.69							
NK	2389-5	Core 2	91.05	1.23	<0.40	<0.63	1.37	<0.42	3.35	<0.47	<0.85	<0.69							
NK	2389-5	Glaze 1	66.75	2.58	<0.40	<0.63	7.15	2.24	17.72	<0.47	<0.85	<0.69				3.57			
NK	2389-5	Glaze 2	70.58	1.75	1.48	<0.63	<0.83	1.07	16.64	<0.47	<0.85	<0.69		1.05		7.43			

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2389-5	Interparticle 1	84.39	1.39	0.52	<0.63	2.90	0.51	4.68	<0.47	<0.85	<0.69				5.62			
NK	2389-5	Interparticle 2	68.88	3.94	<0.40	<0.63	2.97	2.42	21.57	<0.47	<0.85	<0.69						2.11	
NK	2389-6	Core 1	96.57	0.90	<0.40	0.34	0.06	0.29	<0.65	<0.47	0.58	<0.69							
NK	2389-6	Core 2	88.82	1.23	0.28	0.43	0.07	0.32	<0.65	<0.47	7.85	<0.69							
NK	2389-6	Glaze 1	88.00	1.06	<0.40	0.22	<0.83	0.24	<0.65	<0.47	13.44	<0.69							
NK	2389-6	Glaze 2	87.03	0.95	0.09	0.22	0.07	0.24	<0.65	<0.47	10.31	<0.69							
NK	2389-6	Interparticle 1	88.32	<0.29	<0.40	<0.63	<0.83	<0.42	<0.65	<0.47	10.94	<0.69						2.11	
NK	2389-6	Interparticle 2	92.87	1.01	<0.40	0.20	<0.83	0.23	<0.65	<0.47	5.81	<0.69							
NK	2389-7	Core 1	92.17	0.93	<0.40	<0.63	<0.83	<0.42	1.27	<0.47	1.63	<0.69						1.59	
NK	2389-7	Core 2	93.41	1.18	<0.40	0.31	0.06	0.25	<0.65	<0.47	3.85	<0.69							
NK	2389-7	Glaze 1	92.43	0.94	0.09	0.29	0.04	0.31	<0.65	<0.47	4.70	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2389-7	Glaze 2	93.25	1.04	<0.40	0.19	0.17	0.27	<0.65	<0.47	4.24	<0.69							
NK	2389-7	Interparticle 1	88.65	1.13	0.73	0.24	0.02	0.48	<0.65	<0.47	7.04	<0.69				1.70			
NK	2389-7	Interparticle 2	92.45	1.02	<0.40	0.32	<0.83	0.31	<0.65	<0.47	3.38	<0.69							
NK	2389-8	Core 1	96.79	0.94	<0.40	0.22	0.09	0.29	<0.65	<0.47	0.25	<0.69							
NK	2389-8	Core 2	97.54	0.76	<0.40	0.19	0.03	0.31	<0.65	<0.47	0.91	<0.69							
NK	2389-8	Glaze 1	83.73	0.89	0.44	0.32	0.06	0.25	<0.65	<0.47	7.88	<0.69				6.44			
NK	2389-8	Glaze 2	81.68	0.97	2.06	0.28	<0.83	0.28	<0.65	<0.47	12.69	<0.69							
NK	2389-8	Interparticle 1	96.71	0.96	0.03	0.29	0.03	0.32	<0.65	<0.47	4.12	<0.69							
NK	2389-8	Interparticle 2	80.86	0.96	1.72	0.28	<0.83	<0.42	<0.65	<0.47	13.04	<0.69				3.14			
NK	2389-9	Core 1	96.47	0.97	<0.40	0.23	0.03	0.32	<0.65	<0.47	0.84	<0.69							
NK	2389-9	Core 2	95.64	0.93	0.26	0.32	0.04	0.24	<0.65	<0.47	2.24	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	2389-9	Glaze 1	82.57	1.01	0.94	0.32	<0.83	0.22	<0.65	<0.47	16.84	<0.69							
NK	2389-9	Glaze 2	77.50	1.09	2.18	0.23	0.02	0.15	<0.65	<0.47	15.17	<0.69				3.66			
NK	2389-9	Interparticle 1	92.47	1.08	0.11	0.27	0.06	0.30	<0.65	<0.47	3.22	<0.69							
NK	2389-9	Interparticle 2	83.75	1.02	1.57	0.34	0.12	0.09	<0.65	<0.47	14.11	<0.69							
NK	2389-10	Core 1	87.13	0.75	0.34	<0.63	<0.83	0.23	<0.65	<0.47	6.19	<0.69				3.34		2.01	
NK	2389-10	Core 2	85.51	1.20	1.97	0.61	0.07	0.14	<0.65	<0.47	6.70	<0.69						2.24	
NK	2389-10	Glaze 1	80.34	0.95	5.06	0.32	0.01	0.08	<0.65	<0.47	11.30	<0.69						1.99	
NK	2389-10	Glaze 2	81.19	1.00	0.32	0.24	<0.83	0.18	<0.65	<0.47	16.34	<0.69						1.16	
NK	2389-10	Interparticle 1	92.09	0.99	0.21	0.28	0.06	0.14	<0.65	<0.47	3.57	<0.69						1.95	
NK	2389-10	Interparticle 2	82.83	1.01	0.54	0.38	<0.83	0.15	<0.65	<0.47	12.21	<0.69				1.67		1.20	
NK	4075-1	Core 1	75.38	1.12	2.82	<0.63	7.03	2.74	<0.65	10.75	<0.85	<0.69						1.65	

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	4075-1	Core 2	62.77	11.50	0.98	<0.63	5.11	11.78	<0.65	<0.47	4.80	<0.69						5.20	
NK	4075-1	Glaze 1	72.02	1.72	5.26	<0.63	<0.83	2.46	1.31	<0.47	18.96	<0.69		1.07					
NK	4075-1	Glaze 2	73.99	0.81	5.14	<0.63	0.33	2.69	<0.65	<0.47	16.12	<0.69						2.22	
NK	4075-1	Interparticle 1	61.15	1.50	10.58	<0.63	9.67	4.48	<0.65	<0.47	9.46	<0.69		2.54				2.10	
NK	4075-1	Interparticle 2	73.60	0.66	3.95	<0.63	7.76	3.23	<0.65	<0.47	9.90	<0.69						2.53	
NK	4075-2	Core 1	92.57	0.86	0.01	<0.63	0.18	<0.42	<0.65	<0.47	2.13	<0.69				4.24			
NK	4075-2	Core 2	89.32	1.18	0.38	<0.63	0.38	<0.42	1.25	<0.47	3.30	<0.69				3.69			
NK	4075-2	Glaze 1	91.12	1.15	0.38	<0.63	0.28	<0.42	<0.65	<0.47	6.69	<0.69				0.38			
NK	4075-2	Glaze 2	83.99	1.39	1.85	<0.63	0.23	<0.42	1.12	<0.47	7.59	<0.69				3.83			
NK	4075-2	Interparticle 1	94.96	0.77	0.45	<0.63	0.10	<0.42	1.93	<0.47	4.42	<0.69							
NK	4075-2	Interparticle 2	83.74	0.96	7.27	<0.63	0.44	<0.42	1.96	<0.47	3.01	<0.69				2.61			

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	4075-3	Core 1	84.78	1.27	1.24	<0.63	7.57	<0.42	1.99	<0.47	5.41	<0.69							
NK	4075-3	Core 2	74.33	1.20	2.05	<0.63	12.28	<0.42	2.96	<0.47	8.09	<0.69		0.91					
NK	4075-3	Glaze 1	84.03	1.25	2.15	<0.63	0.05	<0.42	0.88	<0.47	11.84	<0.69							
NK	4075-3	Glaze 2	69.68	1.02	4.22	<0.63	0.15	<0.42	0.43	<0.47	16.09	<0.69		2.03		6.22			
NK	4075-3	Interparticle 1	83.36	0.80	2.18	<0.63	<0.83	<0.42	0.79	<0.47	10.53	<0.69				2.33			
NK	4075-3	Interparticle 2	71.44	0.91	3.60	<0.63	11.94	<0.42	0.48	<0.47	9.56	<0.69		1.36		0.71			
NK	4075-4	Core 1	90.61	1.03	0.47	<0.63	<0.83	0.32	<0.65	<0.47	6.48	<0.69				1.09			
NK	4075-4	Core 2	82.91	0.99	0.99	<0.63	4.60	1.05	0.57	<0.47	6.44	<0.69						2.76	
NK	4075-4	Glaze 1	76.84	1.77	1.25	<0.63	<0.83	0.27	<0.65	<0.47	21.79	<0.69							
NK	4075-4	Glaze 2	72.82	0.84	0.86	<0.63	<0.83	0.17	0.19	<0.47	17.20	<0.69				6.68		1.24	
NK	4075-4	Interparticle 1	80.86	0.94	0.53	<0.63	7.63	1.14	0.51	<0.47	6.98	<0.69						4.05	

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
NK	4075-4	Interparticle 2	80.50	0.63	0.34	<0.63	0.12	0.52	0.13	<0.47	11.73	<0.69				4.06		1.98	
NK	4075-5	Core 1	93.28	0.86	<0.40	<0.63	0.28	0.34	0.49	<0.47	0.96	<0.69						1.37	
NK	4075-5	Core 2	91.11	0.82	0.12	<0.63	0.70	0.32	0.42	<0.47	3.61	<0.69				1.37		1.53	
NK	4075-5	Glaze 1	82.90	0.75	0.07	<0.63	1.87	0.12	<0.65	<0.47	7.13	<0.69				5.78		1.38	
NK	4075-5	Glaze 2	82.95	0.94	0.95	<0.63	1.58	0.14	0.37	<0.47	9.26	<0.69				2.53		1.27	
NK	4075-5	Interparticle 1	87.67	0.78	<0.40	<0.63	1.69	0.10	0.30	<0.47	5.53	<0.69				2.82		1.12	
NK	4075-5	Interparticle 2	76.69	0.64	8.68	<0.63	1.13	0.15	0.19	<0.47	5.89	<0.69				5.81		0.83	
SIP	2385-1	Core 1	95.10	0.78	<0.40	0.25	0.02	0.31	0.02	<0.47	0.58	0.09							
SIP	2385-1	Core 2	80.16	0.97	0.99	0.07	1.08	1.70	0.78	<0.47	13.73	0.04							
SIP	2385-1	Glaze 1	76.08	0.56	0.35	<0.63	<0.83	0.19	0.11	<0.47	20.35	<0.69							
SIP	2385-1	Glaze 2	67.57	0.66	1.30	0.02	<0.83	0.19	0.88	<0.47	27.43	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
SIP	2385-1	Interparticle 1	82.07	1.27	0.98	0.20	0.03	0.51	1.41	<0.47	16.05	0.05							
SIP	2385-1	Interparticle 2	77.78	0.74	0.72	0.06	3.94	2.98	0.40	<0.47	10.86	0.09							
SIP	2385-2	Core 1	74.78	1.89	1.10	0.31	4.54	2.32	3.38	<0.47	10.35	<0.69							
SIP	2385-2	Core 2	96.32	0.88	0.14	0.22	<0.83	0.34	0.61	<0.47	4.21	0.01							
SIP	2385-2	Glaze 1	66.87	0.64	4.71	0.06	13.65	2.48	0.66	<0.47	13.25	0.06							
SIP	2385-2	Glaze 2	90.47	0.92	0.41	0.29	0.13	0.21	0.06	<0.47	7.22	<0.69							
SIP	2385-2	Interparticle 1	82.08	0.93	2.96	0.17	5.46	1.42	0.73	<0.47	6.80	<0.69							
SIP	2385-2	Interparticle 2	94.67	1.08	0.69	0.27	0.11	0.30	0.40	<0.47	4.31	0.03							
SIP	2385-3	Core 1	94.33	0.82	<0.40	0.27	0.21	0.30	0.05	<0.47	1.04	0.01							
SIP	2385-3	Core 2	89.27	1.11	0.29	0.28	2.54	1.70	0.25	<0.47	3.54	0.05							
SIP	2385-3	Glaze 1	87.44	1.12	0.02	0.30	0.22	0.45	0.59	<0.47	7.98	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
SIP	2385-3	Glaze 2	76.09	1.28	3.21	0.28	<0.83	0.26	0.15	<0.47	20.95	<0.69							
SIP	2385-3	Interparticle 1	92.81	0.81	<0.40	0.19	0.05	0.27	<0.65	<0.47	4.34	<0.69							
SIP	2385-3	Interparticle 2	89.50	0.88	1.16	0.31	0.09	0.75	<0.65	<0.47	8.28	<0.69							
SIP	2385-4	Core 1	85.70	1.10	7.76	0.28	0.88	0.46	0.21	<0.47	1.45	<0.69							
SIP	2385-4	Core 2	53.19	1.35	35.99	0.82	4.31	0.60	0.79	<0.47	3.36	0.06							
SIP	2385-4	Glaze 1	54.12	1.57	31.39	0.83	5.07	1.16	1.07	<0.47	5.29	0.05							
SIP	2385-4	Glaze 2	52.84	0.86	33.78	0.44	4.61	0.69	1.38	<0.47	4.13	<0.69							
SIP	2385-4	Interparticle 1	51.98	1.00	38.20	0.33	2.89	0.51	0.67	<0.47	3.45	<0.69							
SIP	2385-4	Interparticle 2	51.15	0.93	37.43	0.45	3.60	0.64	0.92	<0.47	3.79	<0.69							
SIP	2385-5	Core 1	61.16	1.34	25.51	0.41	1.74	1.18	1.32	<0.47	6.01	<0.69							
SIP	2385-5	Core 2	48.83	0.71	46.54	0.25	0.15	<0.42	0.31	<0.47	1.21	0.11							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
SIP	2385-5	Glaze 1	52.23	0.95	37.04	0.29	2.30	0.88	1.20	<0.47	4.42	0.02							
SIP	2385-5	Glaze 2	67.29	1.39	19.66	0.35	0.56	1.01	1.86	<0.47	5.70	0.07							
SIP	2385-5	Interparticle 1	62.81	1.09	23.39	0.30	1.23	1.07	1.78	<0.47	6.23	0.03							
SIP	2385-5	Interparticle 2	55.84	1.05	34.14	0.28	1.71	0.73	0.93	<0.47	4.23	<0.69							
SIP	2385-6	Core 1	81.55	1.10	14.32	0.31	0.32	0.37	0.26	<0.47	0.97	0.05							
SIP	2385-6	Core 2	43.95	16.36	15.32	4.28	0.82	1.92	14.17	<0.47	0.57	0.14							
SIP	2385-6	Glaze 1	73.32	1.47	13.99	0.29	1.74	1.13	1.22	<0.47	4.19	<0.69							
SIP	2385-6	Glaze 2	77.31	1.51	11.73	0.37	0.94	0.83	1.04	<0.47	3.38	0.03							
SIP	2385-6	Interparticle 1	52.00	14.96	10.61	2.49	0.50	4.72	10.96	<0.47	0.71	0.12							
SIP	2385-6	Interparticle 2	71.14	1.28	19.40	0.23	1.98	1.17	1.39	<0.47	5.23	<0.69							
SIP	2385-7	Core 1	63.62	1.42	24.43	0.37	2.75	1.03	1.11	<0.47	4.64	<0.69							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
SIP	2385-7	Core 2	62.34	1.20	23.22	0.30	2.16	1.29	1.51	<0.47	5.26	<0.69							
SIP	2385-7	Glaze 1	55.39	1.24	34.00	0.57	0.76	0.69	0.93	<0.47	3.70	<0.69							
SIP	2385-7	Glaze 2	65.52	1.36	23.66	0.31	1.24	0.97	1.42	<0.47	4.13	0.10							
SIP	2385-7	Interparticle 1	54.98	1.31	33.33	0.30	2.75	1.11	1.39	<0.47	4.88	<0.69							
SIP	2385-7	Interparticle 2	60.74	1.26	26.69	0.33	2.62	0.85	1.08	<0.47	4.23	<0.69							
SIP	2385-8	Core 1	75.11	1.32	13.80	0.34	2.80	1.14	1.17	<0.47	4.96	<0.69							
SIP	2385-8	Core 2	61.82	1.09	26.68	0.41	1.74	0.72	1.40	<0.47	3.84	<0.69							
SIP	2385-8	Glaze 1	63.47	1.25	27.61	0.18	3.03	0.75	0.73	<0.47	4.31	<0.69							
SIP	2385-8	Glaze 2	63.06	1.80	20.30	0.63	4.84	1.79	1.99	<0.47	8.46	<0.69							
SIP	2385-8	Interparticle 1	70.77	1.50	19.20	0.46	2.73	1.05	1.17	<0.47	4.43	<0.69							
SIP	2385-8	Interparticle 2	56.20	0.96	34.64	0.32	2.20	0.68	1.19	<0.47	4.02	0.06							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
SIP	2385-9	Core 1	47.85	0.79	39.94	0.30	1.76	0.50	1.62	<0.47	4.28	<0.69							
SIP	2385-9	Core 2	55.81	1.06	31.10	0.42	2.48	1.09	1.52	<0.47	6.60	0.02							
SIP	2385-9	Glaze 1	50.25	1.11	43.01	0.35	1.91	0.56	0.87	<0.47	3.36	<0.69							
SIP	2385-9	Glaze 2	61.14	1.09	32.26	0.30	1.47	0.73	0.96	<0.47	3.14	<0.69							
SIP	2385-9	Interparticle 1	51.76	1.34	38.10	0.64	3.22	0.95	1.31	<0.47	5.31	<0.69							
SIP	2385-9	Interparticle 2	67.46	1.58	16.36	0.34	3.05	1.49	2.08	<0.47	6.99	<0.69							
SIP	2385-10	Core 1	56.63	1.45	31.50	0.64	2.84	1.08	1.45	<0.47	7.14	<0.69							
SIP	2385-10	Core 2	53.29	0.92	36.85	0.32	1.82	0.48	0.77	<0.47	4.15	<0.69							
SIP	2385-10	Glaze 1	62.93	1.21	24.01	0.35	0.49	0.87	1.26	<0.47	6.41	<0.69							
SIP	2385-10	Glaze 2	62.10	1.24	22.65	0.18	1.92	1.11	1.35	<0.47	6.89	0.10							
SIP	2385-10	Interparticle 1	57.57	1.27	30.70	0.35	1.99	0.78	0.97	<0.47	4.96	0.03							

PERIOD	BEADS	PHASE	SiO_2	Al_2O_3	CaO	MgO	Na_2O	K_2O	Fe_2O_3	TiO_2	CuO	MnO_2	ZnO	SO_3	P_2O_5	Cl	PbO	SnO_2	Sb_2O_5
SIP	2385-10	Interparticle 2	66.86	1.27	24.26	0.33	1.83	0.87	1.20	<0.47	6.08	<0.69							

Appendix H: Summary of SEM-EDS

Garstang Museum

PERIOD CATALOGUE– BEAD # TOMB #	SILICA	ALKALI	COLOURANT	IRON PRILLS	GLAZING METHOD
Middle Kingdom E2130-1 427 A'07	Sand	Plant Ash	Copper	No	Efflorescence
Middle Kingdom E2130-2 427 A'07	Sand	Plant Ash	Copper	Yes	Efflorescence
Middle Kingdom E2130-3 427 A'07	Sand	Plant Ash	Copper	Yes	Efflorescence
Middle Kingdom E2130-4 427 A'07	Sand	Plant Ash	Copper	Yes	Efflorescence
Middle Kingdom E2130-5 427 A'07	Sand	Natron?	Copper	No	Efflorescence
Middle Kingdom E2130-6 427 A'07	Sand	Plant Ash	Copper	Yes	Efflorescence
Middle Kingdom E2130-7 427 A'07	Sand	Plant Ash	Copper	Yes	Efflorescence
Middle Kingdom E2130-8 427 A'07	Sand	Plant Ash	Copper	Yes	Efflorescence
Middle Kingdom E2130-9 427 A'07	Sand	Plant Ash	Copper	No	Efflorescence
Middle Kingdom E2130-10 427 A'07	Sand	Plant Ash	Copper	No	Efflorescence
Middle Kingdom E9384-1 9 A'06	Sand	Plant Ash	Copper	No	Efflorescence

PERIOD CATALOGUE– BEAD # TOMB #	SILICA	ALKALI	COLOURANT	IRON PRILLS	GLAZING METHOD
Middle Kingdom E9384-2 9 A'06	Sand	Plant Ash	Copper/ Manganese	Yes	Cementation
Middle Kingdom E9384-3 9 A'06	Sand	Plant Ash	Copper	No	Cementation
Middle Kingdom E9384-4 9 A'06	Sand	Plant Ash	Copper	No	Efflorescence
Middle Kingdom E9384-5 9 A'06	Sand	Plant Ash	Copper	No	Efflorescence
Middle Kingdom E9384-6 9 A'06	Sand	Plant Ash	Copper/ Manganese	No	Efflorescence
Middle Kingdom E9384-7 9 A'06	Sand	Plant Ash	Copper/ Manganese	No	Efflorescence
Middle Kingdom E9384-8 9 A'06	Sand	Natron?	Copper	No	Cementation
Middle Kingdom E9384-9 9 A'06	Sand	Plant Ash	Copper	No	Efflorescence
Middle Kingdom E9384-10 9 A'06	Sand	Plant Ash	Copper	No	Application/ Not faience throughout, Glazed stone
Middle Kingdom E2435-1 475 A'08	Sand	Plant Ash	Copper	No	Efflorescence
Middle Kingdom E2435-2 475 A'08	Sand	Plant Ash	Copper	Yes	Cementation
Middle Kingdom E2435-3 475 A'08	Sand	Natron?	Copper	Yes	Cementation

PERIOD CATALOGUE– BEAD # TOMB #	SILICA	ALKALI	COLOURANT	IRON PRILLS	GLAZING METHOD
Middle Kingdom E2435-4 475 A'08	Sand	Plant Ash	Copper	No	Cementation
Middle Kingdom E2435-5 475 A'08	Sand	Plant Ash	Copper	No	Cementation
Middle Kingdom 2379-1 359 A'07	Sand	Plant Ash	Copper	No	Cementation
Middle Kingdom 2379-2 359 A'07	Sand	Natron?	Copper	No	Cementation
Middle Kingdom 2379-3 359 A'07	Sand	Natron?	Copper	Yes	Cementation
Middle Kingdom 2379-4 359 A'07	Sand	Plant Ash	Copper	No	Cementation
Middle Kingdom 2379-5 359 A'07	Sand	Natron?	Copper	Yes	Efflorescence
Middle Kingdom 2379-6 359 A'07	Sand	Plant Ash	Copper	No	Efflorescence
Middle Kingdom 2379-7 359 A'07	Sand	Plant Ash	Copper	No	Efflorescence
Middle Kingdom 2379-8 359 A'07	Sand	Plant Ash	Copper/ Manganese	No	Efflorescence
Middle Kingdom 2379-9 359 A'07	Sand	Natron?	Copper/ Manganese	No	Efflorescence
Middle Kingdom 2379-10 359 A'07	Sand	Natron?	Copper	No	Cementation

PERIOD CATALOGUE– BEAD # TOMB #	SILICA	ALKALI	COLOURANT	IRON PRILLS	GLAZING METHOD
Middle Kingdom 2345-1 330 A'07	Sand	Plant Ash	Iron	No	Efflorescence
Middle Kingdom 2345-2 330 A'07	Sand	Plant Ash	Iron	No	Efflorescence
Middle Kingdom 2345-3 330 A'07	Sand	Mixed?	Iron	No	Efflorescence
Middle Kingdom 2345-4 330 A'07	Sand	Mixed?	Iron	No	Efflorescence
Middle Kingdom 2345-5 330 A'07	Sand	Plant Ash	Copper	No	Efflorescence
Middle Kingdom 2345-6 330 A'07	Sand	Plant Ash	Copper	No	Efflorescence
Middle Kingdom 2345-7 330 A'07	Sand	Plant Ash	Copper	Yes	Efflorescence
Middle Kingdom 2345-8 330 A'07	Sand	Plant Ash	Copper	Yes	Efflorescence
Middle Kingdom 2345-9 330 A'07	Sand	Plant Ash	Copper	No	Efflorescence
Middle Kingdom 2345-10 330 A'07	Sand	Plant Ash	Copper	No	Cementation
New Kingdom 2375-1 577 A'08	Sand	Natron?	Copper	No	Efflorescence
New Kingdom 2375-2 577 A'08	Sand	Plant Ash	Copper	No	Efflorescence
New Kingdom 2375-3 577 A'08	Sand	Natron?	Copper	No	Efflorescence

PERIOD CATALOGUE– BEAD # TOMB #	SILICA	ALKALI	COLOURANT	IRON PRILLS	GLAZING METHOD
New Kingdom 2375-4 577 A'08	Sand	Natron?	Copper	No	Cementation
New Kingdom 2375-5 577 A'08	Sand	Plant Ash	Copper	No	Efflorescence
New Kingdom 2375-6 577 A'08	Sand	Plant Ash	Copper	No	Efflorescence
New Kingdom 2375-7 577 A'08	Sand	Plant Ash	Copper	No	Efflorescence
New Kingdom 2375-8 577 A'08	Sand	Plant Ash/ Natron?	Copper	No	Efflorescence
New Kingdom 2375-9 577 A'08	Sand	Plant Ash	Copper	No	Efflorescence
New Kingdom 2375-10 577 A'08	Sand	Plant Ash	Copper	No	Efflorescence
New Kingdom 2344-1 942 A'09	Sand	Plant Ash	Copper/ Manganese	No	Cementation
New Kingdom 2344-2 942 A'09	Sand	Plant Ash	Copper/ Manganese	Yes	Efflorescence
New Kingdom 2344-3 942 A'09	Sand	Plant Ash	Copper	No	Unknown, Mineral?
New Kingdom 2344-4 942 A'09	Sand	Plant Ash	Copper	No	Unknown, Mineral?
New Kingdom 2344-5 942 A'09	Sand	Plant Ash	Copper	No	Unknown, Mineral?
New Kingdom 2344-6 942 A'09	Sand	Plant Ash	Copper	No	Unknown, Mineral?

PERIOD CATALOGUE– BEAD # TOMB #	SILICA	ALKALI	COLOURANT	IRON PRILLS	GLAZING METHOD
New Kingdom 2344-7 942 A'09	Sand	Plant Ash	Copper	No	Unknown, Mineral?
New Kingdom 2344-8 942 A'09	Sand	Plant Ash	Copper	No	Unknown, Mineral?
New Kingdom 2344-9 942 A'09	Sand	Plant Ash	Copper	No	Unknown, Mineral?
New Kingdom 2344-10 942 A'09	Sand	Plant Ash	Copper	No	Unknown, Mineral?
New Kingdom 2389-1 649 A'08	Sand	Mixed?	Iron	No	Efflorescence
New Kingdom 2389-2 649 A'08	Sand	Plant Ash	Iron	No	Efflorescence
New Kingdom 2389-3 649 A'08	Sand	Mixed?	Iron	No	Efflorescence
New Kingdom 2389-4 649 A'08	Sand	Mixed?	Iron	No	Efflorescence
New Kingdom 2389-5 649 A'08	Sand	Plant Ash	Iron	No	Efflorescence
New Kingdom 2389-6 649 A'08	Sand	Natron?	Copper	No	Efflorescence
New Kingdom 2389-7 649 A'08	Sand	Natron?	Copper	No	Efflorescence
New Kingdom 2389-8 649 A'08	Sand	Plant Ash	Copper	No	Efflorescence
New Kingdom 2389-9 649 A'08	Sand	Plant Ash	Copper	No	Efflorescence

PERIOD CATALOGUE– BEAD # TOMB #	SILICA	ALKALI	COLOURANT	IRON PRILLS	GLAZING METHOD
New Kingdom 2389-10 649 A'08	Sand	Plant Ash	Copper	No	Efflorescence
New Kingdom 2384-1 525 A'08	Sand	Plant Ash	Copper	No	Efflorescence
New Kingdom 2384-2 525 A'08	Sand	Plant Ash	Copper	No	Efflorescence
New Kingdom 2384-3 525 A'08	Sand	Plant Ash	Copper	No	Efflorescence
New Kingdom 2384-4 525 A'08	Sand	Plant Ash	Iron	Yes	Cementation
New Kingdom 2384-5 525 A'08	Sand	Plant Ash/ Natron?	Iron/ Lead Antimony	No	Efflorescence
New Kingdom 2384-6 525 A'08	Sand	Plant Ash	Other/Nothing	No	Efflorescence
New Kingdom 2384-7 525 A'08	Sand	Plant Ash	Copper/ Manganese	Yes	Efflorescence
New Kingdom 2384-8 525 A'08	Sand	Mixed?	Copper	Yes	Efflorescence
New Kingdom 2384-9 525 A'08	Sand	Plant Ash	Copper	No	Unknown, Mineral?
New Kingdom 2384-10 525 A'08	Sand	Plant Ash	Copper	No	Efflorescence
New Kingdom 2380-1 492 A'08	Sand	Plant Ash	Copper	No	Cementation
New Kingdom 2380-2 492 A'08	Sand	Plant Ash	Copper/ Manganese	Yes	Efflorescence

PERIOD CATALOGUE– BEAD # TOMB #	SILICA	ALKALI	COLOURANT	IRON PRILLS	GLAZING METHOD
New Kingdom 2380-3 492 A'08	Sand	Plant Ash	Copper/ Manganese	No	Efflorescence
New Kingdom 2380-4 492 A'08	Sand	Plant Ash	Copper	No	Efflorescence
New Kingdom 2380-5 492 A'08	Sand	Plant Ash	Copper	No	Efflorescence
New Kingdom 2380-6 492 A'08	Sand	Plant Ash	Copper	No	Efflorescence
New Kingdom 2380-7 492 A'08	Sand	Plant Ash	Copper	No	Efflorescence
New Kingdom 2380-8 492 A'08	Sand	Plant Ash	Copper	No	Efflorescence
New Kingdom 2380-9 492 A'08	Sand	Plant Ash	Copper	No	Efflorescence
New Kingdom 2380-10 492 A'08	Sand	Plant Ash	Copper	No	Efflorescence
Second Inter. Period 2385-1 458 A'08	Sand	Plant Ash	Copper	No	Cementation
Second Inter. Period 2385-2 458 A'08	Sand	Plant Ash	Copper	No	Efflorescence
Second Inter. Period 2385-3 458 A'08	Sand	Plant Ash	Copper	No	Efflorescence
Second Inter. Period 2385-4 458 A'08	Sand	Plant Ash	Copper	No	Unknown, Mineral?
Second Inter. Period 2385-5 458 A'08	Sand	Plant Ash	Iron	No	Unknown, Mineral?

PERIOD CATALOGUE– BEAD # TOMB #	SILICA	ALKALI	COLOURANT	IRON PRILLS	GLAZING METHOD
Second Inter. Period 2385-6 458 A'08	Sand	Plant Ash	Copper	No	Unknown, Mineral?
Second Inter. Period 2385-7 458 A'08	Sand	Plant Ash	Copper	No	Unknown, Mineral?
Second Inter. Period 2385-8 458 A'08	Sand	Plant Ash	Copper	No	Unknown, Mineral?
Second Inter. Period 2385-9 458 A'08	Sand	Plant Ash	Copper	No	Unknown, Mineral?
Second Inter. Period 2385-10 458 A'08	Sand	Plant Ash	Copper	No	Unknown, Mineral?

Garstang Museum: MSc beads (Hammerle 2008)

PERIOD CATALOGUE– BEAD # TOMB #	SILICA	ALKALI	COLOURANT	IRON PRILLS	GLAZING METHOD
Middle Kingdom E2383-1 498 A'08	Sand	Plant Ash	Copper	No	Cementation
Middle Kingdom E2383-2 498 A'08	Sand	Plant Ash	Copper	No	Efflorescence
Middle Kingdom E2383-3 498 A'08	Sand	Plant Ash	Copper	No	Cementation
Middle Kingdom E2383-4 498 A'08	Sand	Plant Ash	Copper	No	Efflorescence
Middle Kingdom E2383-5 498 A'08	Sand	Plant Ash	Copper	No	Efflorescence
Middle Kingdom E2383-6 498 A'08	Sand	Plant Ash	Copper	No	Cementation

PERIOD CATALOGUE– BEAD # TOMB #	SILICA	ALKALI	COLOURANT	IRON PRILLS	GLAZING METHOD
New Kingdom E2377-1 541 A'08	Sand	Plant Ash	Copper	No	Unknown, Mineral?
New Kingdom E2377-2 541 A'08	Sand	Plant Ash	Copper	Yes	Efflorescence
New Kingdom E2377-3 541 A'08	Sand	Plant Ash	Copper	Yes	Efflorescence
New Kingdom E2377-4 541 A'08	Sand	Plant Ash	Iron	Yes	Efflorescence
New Kingdom E2377-5 541 A'08	Sand	Natron?	Copper	No	Cementation

Manchester Museum

PERIOD CATALOGUE– BEAD # TOMB #	SILICA	ALKALI	COLOURANT	IRON PRILLS	GLAZING METHOD
New Kingdom 4075-1 18 A'08	Sand	Plant Ash	Copper	No	Efflorescence
New Kingdom 4075-2 18 A'08	Sand	Plant Ash	Copper	Yes	Efflorescence
New Kingdom 4075-3 18 A'08	Sand	Plant Ash	Copper	No	Efflorescence
New Kingdom 4075-4 18 A'08	Sand	Plant Ash	Copper	No	Efflorescence
New Kingdom 4075-5 18 A'08	Sand	Plant Ash	Copper	No	Efflorescence

Bolton Museum

PERIOD CATALOGUE– BEAD # TOMB #	SILICA	ALKALI	COLOURANT	IRON PRILLS	GLAZING METHOD
Middle Kingdom 54.00.75-1 E 105	Sand	Plant Ash	Copper	No	Unknown, Mineral?
Middle Kingdom 54.00.75-2 E 105	Sand	Plant Ash	Copper	No	Unknown, Mineral?
Middle Kingdom 54.00.75-3 E 105	Sand	Plant Ash	Copper	No	Cementation
Middle Kingdom 54.00.75-4 E 105	Sand	Plant Ash	Copper/ Manganese	No	Efflorescence
Middle Kingdom 54.00.75-5 E 105	Sand	Plant Ash	Copper/ Manganese	No	Unknown, Mineral?
Middle Kingdom 54.00.75-6 E 105	Sand	Plant Ash	Iron/ Manganese	No	Unknown, Mineral?
Middle Kingdom 54.00.75-7 E 105	Sand	Plant Ash	Copper	No	Cementation
Middle Kingdom 54.00.75-8 E 105	Sand	Natron?	Copper	No	Unknown, Mineral?
Middle Kingdom 54.00.75-9 E 105	Sand	Plant Ash	Copper	No	Unknown, Mineral?
Middle Kingdom 54.00.75-10 E 105	Sand	Plant Ash	Copper	No	Unknown, Mineral?
Middle Kingdom 54.00.79-1 E 330	Sand	Plant Ash	Copper	Yes	Efflorescence
Middle Kingdom 54.00.79-2 E 330	Sand	Plant Ash	Copper	No	Efflorescence

PERIOD CATALOGUE– BEAD # TOMB #	SILICA	ALKALI	COLOURANT	IRON PRILLS	GLAZING METHOD
Middle Kingdom 54.00.79-3 E 330	Sand	Plant Ash	Copper	No	Efflorescence
Middle Kingdom 54.00.79-4 E 330	Sand	Plant Ash	Copper	Yes	Efflorescence
Middle Kingdom 54.00.79-5 E 330	Sand	Plant Ash	Copper	Yes	Efflorescence
Middle Kingdom 54.00.79-6 E 330	Sand	Plant Ash	Copper	Yes	Efflorescence
Middle Kingdom 54.00.79-7 E 330	Sand	Plant Ash	Copper	No	Efflorescence
Middle Kingdom 54.00.79-8 E 330	Sand	Plant Ash	Copper	No	Efflorescence
Middle Kingdom 54.00.79-9 E 330	Sand	Plant Ash	Copper	No	Efflorescence
Middle Kingdom 54.00.79-10 E 330	Sand	Plant Ash	Copper	No	Efflorescence
Middle Kingdom 54.00.79?-1 E 330	Sand	Plant Ash	Copper	No	Efflorescence
Middle Kingdom 54.00.79?-2 E 330	Sand	Plant Ash	Copper	Yes	Efflorescence
Middle Kingdom 54.00.79?-3 E 330	Sand	Plant Ash	Copper	Yes	Efflorescence
Middle Kingdom 54.00.79?-4 E 330	Sand	Plant Ash	Copper	Yes	Efflorescence
Middle Kingdom 54.00.79?-5 E 330	Sand	Natron?	Copper	Yes	Cementation

PERIOD CATALOGUE– BEAD # TOMB #	SILICA	ALKALI	COLOURANT	IRON PRILLS	GLAZING METHOD
Middle Kingdom 54.00.79?-6 E 330	Sand	Plant Ash	Copper	Yes	Efflorescence
Middle Kingdom 54.00.79?-7 E 330	Sand	Plant Ash	Copper	No	Efflorescence
Middle Kingdom 54.00.79?-8 E 330	Sand	Plant Ash	Copper	No	Efflorescence
Middle Kingdom 54.00.79?-9 E 330	Sand	Plant Ash	Copper	Yes	Efflorescence
Middle Kingdom 54.00.79?-10 E 330	Sand	Natron?	Copper	No	Cementation

Appendix I: Published Strontium Isotope Analysis on Glass

Publication	SITE	SAMPLE #	PERIOD	MATERIAL	Sr PPM	$^{87}Sr/^{86}Sr$ RATIO	CALCIUM
Freestone 2003	Bet Eli'ezer	6831-1-Q	6th-8th	Glass	322	0.708979	6.00
Freestone 2003	Bet Eli'ezer	6831-3-X	6th-8th	Glass	346	0.709050	7.30
Freestone 2003	Bet Eli'ezer	6831-2-T	6th-8th	Glass	420	0.709053	6.70
Freestone 2003	Bet Eli'ezer	6831-217-Q	6th-8th	Glass	494	0.708912	8.80
Freestone 2003	Bet Eli'ezer	6831-226-T	6th-8th	Glass	503	0.708937	8.10
Freestone 2003	Bet Eli'ezer	6831-221-W	6th-8th	Glass	456	0.708956	8.00
Freestone 2003	Tel el Ashmunein	23249Z	8th-9th	Glass	143	0.707959	9.50
Freestone 2003	Tel el Ashmunein	23247S	8th-9th	Glass	200	0.707940	10.90
Freestone 2003	Tel el Ashmunein	23248Q	8th-9th	Glass	158	0.707979	10.10
Freestone 2003	Banias	6831-61-T	10/11th-13th	Glass	403	0.707723	7.80
Freestone 2003	Banias	6831-62-X	10/11th-13th	Glass	393	0.707797	7.60

Publication	SITE	SAMPLE #	PERIOD	MATERIAL	Sr PPM	$^{87}Sr/^{86}Sr$ RATIO	CALCIUM
Freestone 2003	Banias	6831-63-K	10/11th-13th	Glass	374	0.707734	10.20
Henderson *et al.* 2005	al-Raqqa	Raq 33-34 c	8th-9th	Plant Ash Glass	517	0.708178	
Henderson *et al.* 2005	al-Raqqa	Raq 33-34 p	8th-9th	Plant Ash Glass	503	0.708090	
Henderson *et al*. 2005	al-Raqqa	Raq 45-46	8th-9th	Plant Ash Glass	542	0.708148	
Henderson *et al*. 2005	al-Raqqa	Raq 50	8th-9th	Plant Ash Glass	325	0.708208	
Henderson *et al*. 2005	al-Raqqa	Raq 54	8th-9th	Plant Ash Glass	628	0.708121	
Henderson *et al.* 2005	al-Raqqa	Raq 56	8th-9th	Plant Ash Glass	415	0.707936	
Henderson *et al.* 2005	al-Raqqa	Raq 62	8th-9th	Plant Ash Glass	494	0.708374	
Henderson *et al.* 2005	al-Raqqa	Raq 51-52	8th-9th	Natron Glass	445	0.708844	
Henderson *et al.* 2005	al-Raqqa	Raq 55 b	8th-9th	Natron Glass	392	0.709009	
Henderson *et al.* 2005	al-Raqqa	Raq 63	8th-9th	Natron Glass	409	0.708968	
Henderson *et al.* 2005	al-Raqqa	Raq 68	8th-9th	Natron Glass	385	0.709029	
Leslie *et al.* 2006	Beth Eli'ezer	6831-1-Q	6th-8th	Natron Glass		0.708979	6.00

Publication	SITE	SAMPLE #	PERIOD	MATERIAL	Sr PPM	$^{87}Sr/^{86}Sr$ RATIO	CALCIUM
Leslie *et al.* 2006	Beth Eli'ezer	6831-2-T	6th-8th	Natron Glass		0.709053	6.70
Leslie *et al.* 2006	Beth Eli'ezer	6831-3-X	6th-8th	Natron Glass		0.709050	7.30
Leslie *et al.* 2006	Beth She'an	6831-217-Q	6th-7th	Natron Glass		0.708912	8.80
Leslie *et al.* 2006	Beth She'an	6831-221-W	6th-7th	Natron Glass		0.708956	8.00
Leslie *et al.* 2006	Beth She'an	6831-226-T	6th-7th	Natron Glass		0.708937	8.10
Leslie *et al.* 2006	Tel el Ashmunein	23247S	8th-9th	Natron Glass		0.707940	10.90
Leslie *et al.* 2006	Tel el Ashmunein	23248Q	8th-9th	Natron Glass		0.707979	10.10
Leslie *et al.* 2006	Tel el Ashmunein	23249Z	8th-9th	Natron Glass		0.707959	9.50
Leslie *et al.* 2006	Carthage	32831X	4th-6th	Natron Glass		0.708858	6.40
Leslie *et al.* 2006	Carthage	32832V	4th-6th	Natron Glass		0.708138	5.00
Leslie *et al.* 2006	Carthage	33027W	4th-6th	Natron Glass		0.708079	5.20
Leslie *et al.* 2006	Tyre	7230-3	10th-12th	Plant Ash Glass		0.708155	11.90
Leslie *et al.* 2006	Tyre	7230-8	10th-12th	Plant Ash Glass		0.708149	12.10

Publication	SITE	SAMPLE #	PERIOD	MATERIAL	Sr PPM	$^{87}Sr/^{86}Sr$ RATIO	CALCIUM
Leslie *et al.* 2006	Tyre	7230-13	10th-12th	Plant Ash Glass		0.708116	9.10
Leslie *et al.* 2006	Banias	6831-61-T	10/11th-13th	Plant Ash Glass		0.707723	7.80
Leslie *et al.* 2006	Banias	6831-62-X	10/11th-13th	Plant Ash Glass		0.707797	7.60
Leslie *et al.* 2006	Banias	6831-63-K	10/11th-13th	Plant Ash Glass		0.707734	10.20
Leslie *et al.* 2006	Ra's al-Hadd	35444S	10th-13th	Plant Ash Glass		0.713924	6.50
Leslie *et al.* 2006	Ra's al-Hadd	35448V	10th-13th	Plant Ash Glass		0.708819	10.0
Leslie *et al.* 2006	Ra's al-Hadd	35502Y	10th-13th	Plant Ash Glass		0.708282	6.10
Degryse and Schneider 2008	Tienen, Belgium	TIE2-A-7	1st-3rd Century AD	Natron Glass		0.71923	
Degryse and Schneider 2008	Antwerp, Belgium	ANT-M12	1st-3rd Century AD	Natron Glass		0.71487	
Degryse and Schneider 2008	Wadi-el-Natrun, Egypt	FAZDA 1	1st-3rd Century AD	Natron Glass		0.71046	
Degryse and Schneider 2008	Wadi-el-Natrun, Egypt	FAZDA 2	1st-3rd Century AD	Natron Glass		0.70951	
Degryse and Schneider 2008	River Belus, Levant	BRILL 674	1st-3rd Century AD	Natron Glass		0.71159	
Degryse and Schneider 2008	River Belus, Levant	BRILL 679	1st-3rd Century AD	Natron Glass		0.70920	

Publication	SITE	SAMPLE #	PERIOD	MATERIAL	Sr PPM	$^{87}Sr/^{86}Sr$ RATIO	CALCIUM
Degryse and Schneider 2008	River Belus, Levant	BRILL 681	1st-3rd Century AD	Natron Glass		0.70925	
Degryse and Schneider 2008	River Volturno, Italy	BRILL 4553	1st-3rd Century AD	Natron Glass		0.70969	
Degryse and Schneider 2008	River Volturno, Italy	BRILL 4556	1st-3rd Century AD	Natron Glass		0.70922	
Degryse and Schneider 2008	River Volturno, Italy	BRILL 4554	1st-3rd Century AD	Natron Glass		0.70796	
Degryse and Schneider 2008	Maastricht, Netherlands	Ma 1 c	1st-3rd Century AD	Natron Glass		0.70875	
Degryse and Schneider 2008	Maastricht, Netherlands	Ma 2 b	1st-3rd Century AD	Natron Glass		0.70898	
Degryse and Schneider 2008	Tienen, Belgium	Tie 11	1st-3rd Century AD	Natron Glass	55	0.70893	
Degryse and Schneider 2008	Tienen, Belgium	Tie 12	1st-3rd Century AD	Natron Glass	131	0.70899	
Degryse and Schneider 2008	Tienen, Belgium	Tie 17	1st-3rd Century AD	Natron Glass	363	0.70902	
Degryse and Schneider 2008	Tienen, Belgium	Tie 24	1st-3rd Century AD	Natron Glass	266	0.70902	
Degryse and Schneider 2008	Tienen, Belgium	Tie 35	1st-3rd Century AD	Natron Glass	186	0.70886	
Degryse and Schneider 2008	Tienen, Belgium	Tie 37	1st-3rd Century AD	Natron Glass	241	0.70891	
Degryse and Schneider 2008	Tienen, Belgium	Tie 41	1st-3rd Century AD	Natron Glass	363	0.70901	

Publication	SITE	SAMPLE #	PERIOD	MATERIAL	Sr PPM	$^{87}Sr/^{86}Sr$ RATIO	CALCIUM
Degryse and Schneider 2008	Tienen, Belgium	Tie 45	1st-3rd Century AD	Natron Glass	304	0.70904	
Degryse and Schneider 2008	Tienen, Belgium	Tie 48	1st-3rd Century AD	Natron Glass	355	0.70896	
Degryse and Schneider 2008	Tienen, Belgium	Tie 49	1st-3rd Century AD	Natron Glass	241	0.70759	
Degryse and Schneider 2008	Tienen, Belgium	Tie 50	1st-3rd Century AD	Natron Glass	241	0.70898	
Degryse and Schneider 2008	Bocholtz, Netherlands	Bo 106	1st-3rd Century AD	Natron Glass	283	0.70905	
Degryse and Schneider 2008	Bocholtz, Netherlands	Bo 109	1st-3rd Century AD	Natron Glass	229	0.70903	
Degryse and Schneider 2008	Bocholtz, Netherlands	Bo 119	1st-3rd Century AD	Natron Glass	279	0.70958	
Degryse and Schneider 2008	Bocholtz, Netherlands	Bo 123	1st-3rd Century AD	Natron Glass	340	0.70906	
Degryse and Schneider 2008	Kelemantia, Slovakia	Kel 82/91	1st-3rd Century AD	Natron Glass		0.70904	
Degryse and Schneider 2008	Kelemantia, Slovakia	Kel 229/06	1st-3rd Century AD	Natron Glass		0.70901	
Degryse and Schneider 2008	Kelemantia, Slovakia	Kel 229/88	1st-3rd Century AD	Natron Glass		0.70877	
Degryse and Schneider 2008	Kelemantia, Slovakia	Kel 234/88	1st-3rd Century AD	Natron Glass		0.70966	
Degryse and Schneider 2008	Sagalassos, Turkey	Sag 573	1st-3rd Century AD	Natron Glass		0.70865	

Publication	SITE	SAMPLE #	PERIOD	MATERIAL	Sr PPM	$^{87}Sr/^{86}Sr$ RATIO	CALCIUM
Degryse and Schneider 2008	Sagalassos, Turkey	Sag 574	1st-3rd Century AD	Natron Glass	330	0.70905	
Degryse and Schneider 2008	Sagalassos, Turkey	Sag 709	1st-3rd Century AD	Natron Glass		0.70910	
Degryse and Schneider 2008	Sagalassos, Turkey	Sag 575	1st-3rd Century AD	Natron Glass		0.70894	
Degryse and Schneider 2008	Sagalassos, Turkey	Sag 717	1st-3rd Century AD	Natron Glass		0.70879	
Degryse and Schneider 2008	Sagalassos, Turkey	Sag 718	1st-3rd Century AD	Natron Glass		0.70882	
Degryse *et al.* 2010 a	Nuzi	1930.82.17	14th Century BC	Glass		0.70838	4.80
Degryse *et al.* 2010 a	Nuzi	1930.82.50	14th Century BC	Glass		0.70837	8.58
Degryse *et al.* 2010 a	Nuzi	1930.66.90b	14th Century BC	Glass		0.70843	8.93
Degryse *et al.* 2010 a	Tell Brak	TB1	14th Century BC	Glass		0.70839	8.50
Degryse *et al.* 2010 a	Tell Brak	TB2	14th Century BC	Glass		0.70810	6.10
Degryse *et al.* 2010 a	Tell Brak	TB10	14th Century BC	Glass		0.70821	4.70
Degryse *et al.* 2010 a	Malkata, Egypt	UPP31	14th Century BC	Glass		0.70785	6.30
Degryse *et al.* 2010 a	Malkata, Egypt	UPP33	14th Century BC	Glass		0.70780	7.50

Publication	SITE	SAMPLE #	PERIOD	MATERIAL	Sr PPM	$^{87}Sr/^{86}Sr$ RATIO	CALCIUM
Degryse *et al.* 2010 a	Malkata, Egypt	UPP39	14th Century BC	Glass		0.70793	8.80
Degryse *et al.* 2010 a	Malkata, Egypt	UPP40	14th Century BC	Glass		0.70793	4.90
Degryse *et al.* 2010 a	Malkata, Egypt	UPP30	14th Century BC	Glass		0.70787	9.20
Degryse *et al.* 2010 a	Malkata, Egypt	UPP5	14th Century BC	Glass		0.70805	8.60
Degryse *et al.* 2010 b	Banias, Israel	BAN 49	9th - 10th Century AD	Glass		0.70778	9.77
Degryse *et al.* 2010 b	Banias, Israel	BAN 51	9th - 10th Century AD	Glass		0.70766	8.42
Degryse *et al.* 2010 b	Banias, Israel	BAN 61	9th - 10th Century AD	Glass		0.70762	7.83
Degryse *et al.* 2010 b	Banias, Israel	BAN 62	9th - 10th Century AD	Glass		0.70773	7.61
Degryse *et al.* 2010 b	Banias, Israel	BAN 63	9th - 10th Century AD	Glass		0.70770	10.19
Degryse *et al.* 2010 b	Banias, Israel	BAN 58	9th - 10th Century AD	Glass		0.70802	9.69
Degryse *et al.* 2010 b	Tyre, Lebanon	TYRE 3	9th - 10th Century AD	Plant Ash Glass		0.70812	11.93
Degryse *et al.* 2010 b	Tyre, Lebanon	TYRE 8	9th - 10th Century AD	Plant Ash Glass		0.70812	12.06
Degryse *et al.* 2010 b	Tyre, Lebanon	TYRE 9 GLASS	9th - 10th Century AD	Plant Ash Glass		0.70817	5.14

Publication	SITE	SAMPLE #	PERIOD	MATERIAL	Sr PPM	$^{87}Sr/^{86}Sr$ RATIO	CALCIUM
Degryse *et al.* 2010 b	Tyre, Lebanon	TYRE12	9th - 10th Century AD	Plant Ash Glass		0.70846	9.04
Degryse *et al.* 2010 b	Tyre, Lebanon	TYRE 13	9th - 10th Century AD	Plant Ash Glass		0.70811	9.11
Degryse *et al.* 2010 b	Tyre, Lebanon	TYRE 9 QUARTZ	9th - 10th Century AD	Qartz		0.70824	
Henderson *et al.* 2010	Brak, Mesopotamia	Brak-01	14th Century BC	Glass	412	0.70849	8.35
Henderson *et al.* 2010	Brak, Mesopotamia	Brak-02	14th Century BC	Glass	449	0.70798	
Henderson *et al.* 2010	Brak, Mesopotamia	Brak-08	14th Century BC	Glass	340	0.70829	
Henderson *et al.* 2010	Brak, Mesopotamia	Brak-09	14th Century BC	Glass	308	0.70813	5.82
Henderson *et al.* 2010	Brak, Mesopotamia	Brak-12	14th Century BC	Glass	407	0.70871	
Henderson *et al.* 2010	Brak, Mesopotamia	Brak-14	14th Century BC	Glass	280	0.70856	4.98
Henderson *et al.* 2010	Brak, Mesopotamia	Brak-16	14th Century BC	Glass	330	0.70867	6.04
Henderson *et al.* 2010	Brak, Mesopotamia	Brak-17	14th Century BC	Glass	324	0.70859	
Henderson *et al.* 2010	Amarna, Egypt	Am-03	14th Century BC	Glass	1068	0.70791	6.90
Henderson *et al.* 2010	Amarna, Egypt	Am-04	14th Century BC	Glass	332	0.70798	4.15

Publication	SITE	SAMPLE #	PERIOD	MATERIAL	Sr PPM	$^{87}Sr/^{86}Sr$ RATIO	CALCIUM
Henderson *et al.* 2010	Amarna, Egypt	Am-05	14th Century BC	Glass	346	0.70817	6.20
Henderson *et al.* 2010	Amarna, Egypt	Am-06	14th Century BC	Glass	756	0.70803	7.46
Henderson *et al.* 2010	Amarna, Egypt	Am-07	14th Century BC	Glass	526	0.70805	7.80
Henderson *et al.* 2010	Amarna, Egypt	Am-09	14th Century BC	Glass	1275	0.70788	8.90
Henderson et al. 2010	Athens, Greece	KN 1	15th Century BC	Glass	295	0.70825	4.52
Henderson *et al.* 2010	Thebes, Greece	MK 1966	13th Century BC	Glass	367	0.70793	4.65
Henderson *et al.* 2010	Elateia, Greece	KN-98-224	11th Century BC	Glass	308	0.70795	
Henderson *et al.* 2010	Thebes, Greece	KN-P-134-251	13th Century BC	Glass	880	0.70803	7.25
Henderson *et al.* 2010	Elateia, Greece	KN-96-216	14th Century BC	Glass	516	0.70793	6.54
Henderson *et al.* 2010	Thebes, Greece	KN-138-121	13th Century BC	Glass	922	0.70790	
Henderson *et al.* 2010	Elateia, Greece	KN-I-69-132	12th Century BC	Glass	597	0.70800	5.14
Henderson *et al.* 2010	Elateia, Greece	KN-I-69-126	12th Century BC	Glass	390	0.70800	5.11
Henderson *et al.* 2010	Atalanti-Spartia, Greece	KN-18-39	12th Century BC	Glass	392	0.70790	7.25

Publication	SITE	SAMPLE #	PERIOD	MATERIAL	Sr PPM	$^{87}Sr/^{86}Sr$ RATIO	CALCIUM
Henderson *et al.* 2010	Thebes, Greece	KN-M-100-363	13th Century BC	Glass	3035	0.70795	5.25

Appendix J: Recipes of Replica Batches

Batch 1: Efflorescence Glaze

Si 90 g (Japanese Garden Centre)

Ca 3 g (Garden Lime)

Na 4 g (Sodium)

Cu 3 g (Metallic Copper Pipe)

Fired: 850^{o} C for 30 minutes

Results: Turquoise blue tint, very granular, no glaze on the bottom of the bead, very sandy in texture, core is neither stable nor shows signs of vitrification.

Batch 2: Efflorescence Glaze

Si 90 g (Ainsdale Wet)

Ca 3 g (Garden Lime)

Na 4 g (Sodium)

Cu 3 g (Metallic Copper Pipe)

Fired: 850^{o} C for 30 minutes

Results: Fire hardened, very little blue colour, no glaze, and falling apart.

Batch 3: Efflorescence Glaze

Si 90 g (Japanese Garden Centre)

Ca 3 g (Garden Lime)

Na 4 g (Sodium)

Cu 3 g (Metallic Copper Pipe)

Fired: 900^{o} C for 30 minutes

Results: The core dropped out, the particles are not well mixed, the colour is a bit bluer.

Batch 4: Efflorescence Glaze

Si 90 g (Ainsdale Wet)

Ca 3 g (Garden Lime)

Na 4 g (Sodium)

Cu 3 g (Metallic Copper Pipe)

Fired: 900^{o} C for 30 minutes

Results: Very dark, colour more grey than blue.

Batch 5: Efflorescence Glaze

Si 90 g (Japanese Garden Centre)
Ca 3 g (Garden Lime)
Na 4 g (Sodium)
Cu 3 g (Metallic Copper Pipe)
Fired: 950^{o} C for 30 minutes
Results: Colour is greener blue, started falling apart within days.

Batch 6: Efflorescence Glaze

Si 90 g (Ainsdale Wet)
Ca 3 g (Garden Lime)
Na 4 g (Sodium)
Cu 3 g (Metallic Copper Pipe)
Fired: 1000^{o} C for 30 minutes
Results: Turned to sand, results very blue but friable. Was placed in a desiccator for a week to remove moisture and improve the salts formation. Did not work.

Batch 7: Efflorescence Glaze

Si 50 g (Japanese Garden Centre)
Ca 5 g (Garden Lime)
Na 5 g (Sodium)
Cu 2 g (Metallic Copper Pipe)
Fired: 950^{o} C for 30 minutes
Results: One third of the mixture was fired at the above temperature and length of time. There was too much flux, and the faience melted to the crucible or turned to sand.

Batch 8: Efflorescence Glaze

Si 50 g (Japanese Garden Centre)
Ca 5 g (Garden Lime)
Na 5 g (Sodium)
Cu 2 g (Metallic Copper Pipe)
Fired: 850^{o} C for 45 minutes
Results: The second third of the mixture for Batch 7. This mixture also melted at the lower temperature. Proves there is far too much flux. This is the maximum used.

Batch 9: Efflorescence Glaze

Si 50 g (Japanese Garden Centre)
Ca 5 g (Garden Lime)
Na 5 g (Sodium)
Cu 2 g (Metallic Copper Pipe)
Fired: 850^{o} C for 30 minutes
Results: The remaining third of the mixture for Batch 7, this batch was ground longer to improve the particle size. This batch did not melt. The beads were very light blue, some bits of darker blue glaze forming in areas.

Batch 10: Efflorescence Glaze

Si 50 g (Japanese Garden Centre)
Ca 5 g (Garden Lime)
Na 5 g (Sodium)
Cu 2 g (Metallic Copper Pipe)
Fired: 850^{o} C for 1 hour
Results: Turned blue with some glaze formed in patches. However, eventually turned to sand.

Note: It was at this point that the decision was made that the particle size needed to be finer. The mortar and pestle was not enough. The faience material was not sticking together and there was no structural integrity. Therefore, the mechanical crusher at the Earth and Ocean Science Department was utilised to produce particles between 50-200 microns. All batches after this point are made with fine particles.

Batch 11: Efflorescence Glaze

Si 90 g (Ainsdale Wet)
Ca 4 g (Garden Lime)
Na 4 g (Sodium)
Cu 3 g (Metallic Copper Pipe)
Fired: 850^{o} C for 45 minutes
Results: Very good; the bead is solid and the core is hard. The colour, however, is more reddish than blue.

Batch 12: Efflorescence Glaze

Si 90 g (Japanese Garden Centre)

Ca 3 g (Garden Lime)

Na 4 g (Sodium)

Cu 3 g (Metallic Copper Pipe)

Fired: 850^{o} C for 45 minutes

Results: Powdered

Results: The paste was easy to work. The glaze is blue is slightly spotty throughout. There is a slight shine to the glaze.

Batch 13: Efflorescence Glaze

Si 90 g (Japanese Garden Centre)

Ca 3 g (Garden Lime)

Na 4 g (Sodium)

Cu 3 g (Metallic Copper Pipe)

Fired: 850^{o} C for 1 hour

Results: The glaze is darker and the hardest yet. Very shiny however, the colour is still not homogeneous.

Batch 14: Efflorescence Glaze

Si 90 g (Ainsdale Wet)

Ca 4 g (Garden Lime)

Na 4 g (Sodium)

Cu 3 g (Metallic Copper Pipe)

Fired: 850^{o} C for 1 hour

Results: The glaze is very hard, shiny yet splotchy.

Batch 15: Efflorescence Glaze

Si 90 g (JGC)

Ca 3 g

Na 4 g

Cu 3 g pipe

Fired: 900^{o} C for 45 minutes

Results: This is the best glaze yet, very shiny. However, very spotty. The copper needs to be more homogenous. This bead was selected for SEM-EDS.

Batch 16: Efflorescence Glaze

Si 90 g (Ainsdale Wet)

Ca 4 g (Garden Lime)

Na 4 g (Sodium)

Cu 3 g (Metallic Copper Pipe)

Fired: 900^{o}C for 45 minutes

Results: Closer to the desired blue colour, however the glaze is still not right, it is very hard but has very little glassiness to it.

Batch 17: Efflorescence Glaze

Si 90 g (Ainsdale Wet)

Ca 4 g (Garden Lime)

Na 4 g (Sodium)

Cu 3 g (Metallic Copper Pipe)

Fired: 900^{o}C for 1.5 hours

Results: The glaze was still not right. The colour is a bit more greenish brown than blue. The bead has a burnt look to it. Removed for SEM-EDS analysis.

Batch 18: Efflorescence Glaze

Si 90 g (Japanese Garden Centre)

Ca 3 g (Garden Lime)

Na 4 g (Sodium)

Cu 3 g (Metallic Copper Pipe)

Fired: 900^{o}C for 1 hour

Results: Very good colour, however the glaze is still not vitrified.

Batch 19: Efflorescence Glaze

Si 90 g (Japanese Garden Centre)

Ca 3 g (Garden Lime)

Na 4 g (Sodium)

Cu 3 g (Metallic Copper Pipe)

Fired: 900^{o}C for 1.5 hr

Results: The blue colour is all over the bead, but uneven in distribution. Selected for SEM-EDS analysis.

Batch 20: Efflorescence Glaze

Si 90 g (Japanese Garden Centre)

Ca 3 g (Garden Lime)

Na 4 g (Sodium)

Cu 3 g (Metallic Copper Pipe)

Fired: 850^{o} C for 1.5 hour

Results: The results are the same as Batch 19.

Batch 21: Efflorescence Glaze

Si 45 g (Chelford)

Ca 2 g (Garden Lime)

Na 2 g (Sodium)

Cu 1 g (Metallic Copper Pipe)

Fired: 850^{o} C for 1.45 hours

Results: Very pale blue in colour with darker blue spots of glaze randomly distributed over the bead.

Batch 22: Efflorescence Glaze

Si 45 g (Chelford)

Ca 2 g (Garden Lime)

Na 2 g (Sodium)

Cu 4 g (Metallic Copper Pipe)

Fired: 850^{o} C for 1.45 hour

Results: More copper filings added to enrich the colour. The bead turned out to be very dark green in colour. This was also the first batch to be made using a reed perforation method.

Batch 23: Efflorescence Glaze

Si 45 g (Chelford)

Ca 2 g (Garden Lime)

Na 2 g (Sodium)

Cu 1 g (Metallic Copper Pipe)

Fired: 850^{o} C for 1 hour

Results: Very pale, no real colour observed. No glaze present.

Batch 24: Efflorescence Glaze

Si 45 g (Chelford)

Ca 2 g (Garden Lime)

Na 2 g (Sodium)

Cu 4 g (Cupric Oxide)

Fired: 850^{o} C for 1 hour

Results: Dark green, no colour forming on the side upon which it rested.

Batch 25: Efflorescence Glaze

Si 45 g (Chelford)

Ca 2 g (Garden Lime)

Na 2 g (Sodium)

Cu 4 g (Cupric Oxide)

Fired: 800^{o} C for 30 minutes

Results: There is no glaze, the surface is dark blue/green with darker blue bits. The colour is uneven.

Batch 26: Efflorescence Glaze

Si 45 g (Sinai)

Ca 1.5 g (Garden Lime)

Na 2 g (Sodium)

Cu 1.5 g (Cupric Oxide)

Fired: 900^{o} C for 45 minutes

Results: No glaze has formed. The colour is teal and homogeneous. Covers the whole bead. This bead was sampled for SEM.

Batch 27: Efflorescence Glaze

Si 45 g (Sinai)

Ca 1.5 g (Garden Lime)

Na 2 g (Sodium)

Cu 1.5 g (Cupric Oxide)

Fired: 900^{o} C for 45 minutes

Results: Similar to batch 26 but produced with reeds. The colour is a bit lighter and there is a resting spot. Shows similar reed lines to the archaeological samples.

Batch 28: Efflorescence Glaze

Si 45 g (Sinai)

Ca 2 g (Garden Lime)

Na 1 g (Sodium)

Cu 2 g (Cupric Oxide)

Fired: 950^{o} C for 30 minutes

Results: Even lighter colour than Batch 27. No real glaze.

Batch 29: Efflorescence Glaze

Si 45 g (Sinai)

Ca 2 g (Garden Lime)

Na 1 g (Sodium)

Cu 2 g (Cupric Oxide)

Fired: 900^{o} C for 45 minutes

Results: This bead was left to sit for three days to dry out in the desiccator. The bead turned pale green with darker spots of green, however no real glaze formed.

Batch 30: Efflorescence Glaze

Si 45 g (Sinai)

Ca 2 g (Garden Lime)

Na 1 g (Sodium)

Cu 2 g (Cupric Oxide)

Fired: 850^{o} C for 30 minutes

Results: No variation from the results of Batch 30.

Batch 31: Efflorescence Glaze

Si 45 g (Sinai)

Ca 1.5 g (Garden Lime)

Na 1.5 g (Sodium)

Cu 2 g (Malachite)

Fired: 900^{o} C for 30 minutes

Results: The colour is even throughout the body. No glaze formed. The colour is very close to that seen in archaeological samples.

Batch 32: Efflorescence Glaze

Si 45 g (Sinai)

Ca 1.5 g (Garden Lime)
Na 1.5 g (Sodium)
Cu 2 g (Chalcopyrite)
Fired: 900^{o} C for 1 hour
Results: The colour is even throughout, however it is grey and there is no glassy glaze.

Batch 33: Efflorescence Glaze

Si 45 g (Sinai)
Ca 1.5 g (Garden Lime)
Na 1.5 g (Sodium)
Cu 2 g (Malachite)
Fired: 900^{o} C for 1 hour
Results: Same batch recipe as Batch 31, but instead of water to mix the paste, vinegar was used. A slight fizzing and foaming happened when the vinegar was added to the powder. The beads dried quickly with no slumping. As soon as bead is formed, it was dry and rolled around. The beads were then put in the oven at 30-40^{o} to simulate Egyptian weather conditions to see how the salts would form. When fired the beads turned purple and lacked a glassy glaze.

Batch 34: Efflorescence Glaze

Si 45 g (Sinai)
Ca 1.5 g (Garden Lime)
Na 1.5 g (Sodium)
Cu 2 g (Malachite)
Fired: 900^{o} C for 30 minutes
Results: These beads were oven-dried and made of the same batch recipe as 33 except they were mixed with water. The glaze turned greenish blue. Therefore, there must have been a chemical reaction in Batch 33 to make the bead purple.

Batch 35: Efflorescence Glaze

Si 45 g (Sinai)
Ca 1.5 g (Garden Lime)
Na 1.5 g (Sodium)
Cu 2 g (Malachite)
Fired: 950^{o} C for 2 hour

Results: These beads came out homogeneous and light blue in colour. One was selected for SEM analysis to represent the copper content.

Batch 36: Efflorescence Glaze

Si 45 g (Sinai)
Ca 1.5 g (Garden Lime)
Na 1.5 g (Sodium)
Cu 2 g (Chalcopyrite)
Fired: 950^{o} C for 2 hour
Results: The bead was very matt yellow-green colour, homogeneous, and all around the bead. Selected for SEM-EDS analysis.

Batch 37: Efflorescence

Si 22 g (Quartz)
Ca 1 g (Garden Lime)
Na 1 g (Sodium)
Cu .5 g (Metallic Copper Pipe)
Fired: 950^{o} C for 5 hours
Results: These beads were produced with quartz pebbles collected from Eddisbury Hill. The pebbles were fired for 5 hours at 950^{o} C for 5 hours. They were then crushed using an unfired quartz pebble as the pestle for a mortar. Then the crushed material was sieved down to 100 microns to maintain a small particles size. The workability was not as good as the sand. No visible salts formed but the bead did turn blue, however no glossy glaze.

Batch 38: Efflorescence Glaze

Si 22.5 g (Quartz)
Ca 1 g (Garden Lime)
Na 2 g (Sodium)
Cu .5 g (Metallic Copper Pipe)
Fired: 950^{o} C for 5 hours
Results: This was the start of a mass experiment to produce a glossy glaze. This included Batch 39, 40, and 41. This bead did not have a shiny glaze and the interior colour was whitish and the exterior blue. This bead was sampled for SEM-EDS.

Batch 39: Efflorescence Glaze

Si 45 g (Sinai)
Ca 1.5 g (Garden Lime)
Na 1.5 g (Sodium)
Cu 2 g (Malachite)
Fired: 950^{o} C for 5 hours
Results: Still no glassy glaze however the colour darkened and went all the way through the sample. Sampled for SEM-EDS

Batch 40: Efflorescence Glaze

Si 45 g (Sinai)
Ca 2 g (Garden Lime)
Na 1 g (Sodium)
Cu 2 g (Cupric Oxide)
Fired: 950^{o} C for 5 hours
Results: Still lacks a glossy glaze, however the colour is a homogeneous dark green. Sampled for SEM-EDS.

Batch 41: Efflorescence Glaze

Si 22.5 g (Quartz)
Ca 1 g (Garden Lime)
Na 2 g (Sodium)
Cu .5 g (Cupric Oxide)
Fired: 950^{o} C for 5 hours
Results: The colour of this bead is very light blue, even almost white. The surface is matt in appearance and the core is similar throughout.

Batch 42: Efflorescence Glaze

Si 90 g (Sinai)
Ca 3 g (Garden Lime)
Na 4 g (Sodium)
Cu 3 g (Metallic Copper Pipe)
Fired: Various
Results: This batch was for the Mohs hardness test. The beads were fired from 800-1050^{o} and from 1 hour to 6 hours. The results were similar in light bluish colour and the lack of glaze. The highest and lowest temperature beads were selected for

SEM-EDS analysis at the 5 hour mark to be consistent with the experimental batches 38-41.

Batch 42: Efflorescence and Cementation Glaze

Si 90 g (Sinai)
Ca 3 g (Garden Lime)
Na 4 g (Sodium)
Cu 3 g (Metallic Copper Pipe)
Fired: 950^{o} for 5 hours.
Result: The bead was very matt in appearance and similar to the other beads that were fired at various temperatures, except this one was a bit bluer in colour. The colour went throughout the body with a slight variation in shade at the surface compared to the core.

Batch 43: Efflorescence Glaze

Si 90 g (Sinai)
Ca 3 g (Garden Lime)
Na 4 g (Sodium)
Cu 3 g (Cupric Oxide)
Fired: Various
Results: This batch was for the Mohs hardness test. The beads were fired from 800-1050^{o} and from 1 hour to 6 hours. The results were similar in dark bluish colour and lack of glaze. The highest and lowest temperature beads were selected for SEM-EDS analysis at the 5 hour mark to be consistent with the experimental batches 38-41.

Batch 43: Efflorescence and Cementation Glaze

Si 90 g (Sinai)
Ca 3 g (Garden Lime)
Na 4 g (Sodium)
Cu 3 g (Cupric Oxide)
Fired: 950^{o} for 5 hours.
Result: The bead was very matt in appearance and similar to the other beads that were fired at various temperatures, except this one was a darker bluer in colour. The colour went throughout the body with a slight variation in shade at the surface compared to the core.

Batch 44: Cementation Glaze

Core: 100 g (Sinai)

Glaze: Si 25 g (Sinai)

Ca 12 g (Garden Lime)

Na 10 g (Sodium)

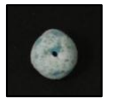
Cu 3 g (Metallic Copper Pipe)

Fired: 950^{o} for 5 hours.

Result: The results were very good. The glaze was not glossy; however in cross section the bead had a blue surface with a white core.

Appendix K: Summary of Experimental Beads

BATCH	MUNSELL	HARDNESS CORE/GLAZE	DESCRIPTION	SILICA	COLOURANT	GLAZING METHOD	PHOTO
15 900° 0.45 hr	Moderate blue 5 B 5/6 Core: Very pale blue 5 B 8/2	3/8	Splotchy blue with darker spots and whitish areas. Glossy glaze.	Japanese Garden Centre	Copper/ metallic shavings	Efflorescence	
17 900° 1.30 hr	Spots light blue 5 B 7/6 with large areas of Dusky blue green 5 BG 3/2 Core: same	3/4	Splotchy bluish dark green, no glaze.	Ainsdale	Copper/ metallic shavings	Efflorescence	
19 900° 1.30 hr	Mostly Moderate blue 5 B 5/6 Core: Bluish white 5 B 9/1	3/5	Slight glaze, splotchy but more homogeneous than Batch 15. Less of a glaze though.	Japanese Garden Centre	Copper/ metallic shavings	Efflorescence	
26 900° 0.45 hr	Dusky blue green Core: same	3/6	No glaze but very homogeneous; more of a dark green colour.	Sinai Sand	Copper/ Cupric Oxide	Efflorescence	
35 950° 2 hr	Not Munsellable	3/4	No glaze but very homogeneous in colour, more purple than blue	Sinai Sand	Copper/ Malachite	Efflorescence	

BATCH	MUNSELL	HARDNESS CORE/GLAZE	DESCRIPTION	SILICA	COLOURANT	GLAZING METHOD	PHOTO
36 950° 2 hr	Olive gray 5 Y 3/2 Core: same	3/4	No glaze, very matt in colour. Homogeneous throughout.	Sinai Sand	Copper/ Chalcopyrite	Efflorescence	
38 950° 5 hr	Light blue 5 B 7/6 Core: Grayish yellow 5 Y 8/4	3/4	No Shiny glaze but different interior colour to interior one	Quartz	Copper/ metallic shavings	Efflorescence	
39 950° 5 hr	Light blue 5 B 7/6 Core: Moderate blue 5 B 5/6	3/4	No Shiny glaze. Core is a darker colour than glaze.	Sinai Sand	Copper/ Malachite	Efflorescence	
40 950° 5 hr	Dusky blue green 5 BG 3/2 Core: same	3/4	No Shiny glaze. Core is a darker colour than glaze.	Sinai Sand	Copper/ Cupric Oxide	Efflorescence	
41 950° 5 hr	Light blue 5 B 7/6 Core: Grayish yellow 5 Y 8/4	3/4	No glossy glaze but core is different in colour. True efflorescence glaze.	Quartz	Copper/ Cupric Oxide	Efflorescence	
42 800° 5 hr	Pale blue 5 B 8/2 Core: same	4/5	Very matt in glaze colour. Some dark blue spots. Core is very similar.	Sinai Sand	Copper/ metallic	Efflorescence	
42 1050° 5 hr	Light blue 5 B 7/6 Core: same	5/6	Same as above	Sinai Sand	Copper/ metallic	Efflorescence	

BATCH	MUNSELL	HARDNESS CORE/GLAZE	DESCRIPTION	SILICA	COLOURANT	GLAZING METHOD	PHOTO
42 950° 5 hr	Light blue 5 B 7/6 Core: same	NA	Glazed but matt. Colour is homogeneous.	Sinai Sand	Copper/ metallic	Efflorescence/ Cementation	
43 800° 5 hr	Moderate blue 5 B 5/6 Very dusky red purple 5 RP 2/2	3/4	Surface is splotchy, dark blue spots with some light spots. Core is dark. Glaze is matt.	Sinai Sand	Copper/ Cupric Oxide	Efflorescence	
43 1050° 5 hr	Light blue 5 B 7/6 Moderate blue 5 B 5/6	5/6	Same as above	Sinai Sand	Copper/ Cupric Oxide	Efflorescence	
43 950° 5 hr	Moderate blue 5 B 5/6 Core: Same	NA	Glazed, matt. Colour is homogeneous.	Sinai Sand	Copper/ Cupric Oxide	Efflorescence/ Cementation	
44 950° 5 hr	Very pale blue 5 B 8/2 Core: bluish white 5 B 9/1	NA	Glaze is blue on the exterior however very matt. The core is very white.	Sinai Sand	Copper/ metallic	Cementation	

Appendix L: Experimental Bead SEM Images

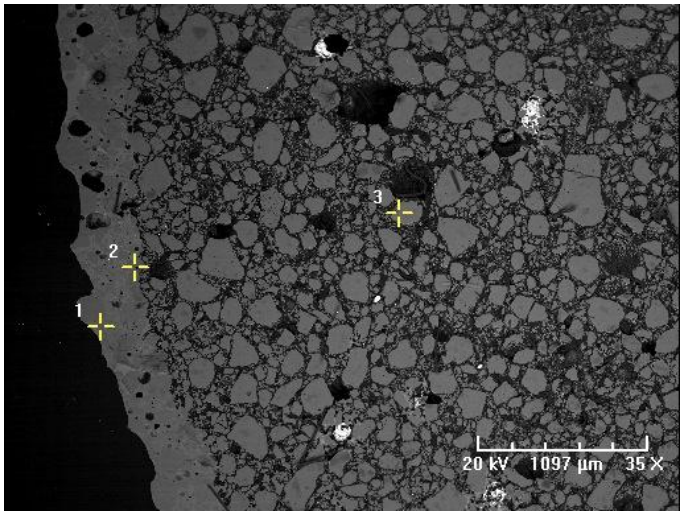


Figure L.1: Profile 1 of Batch 15, efflorescence.

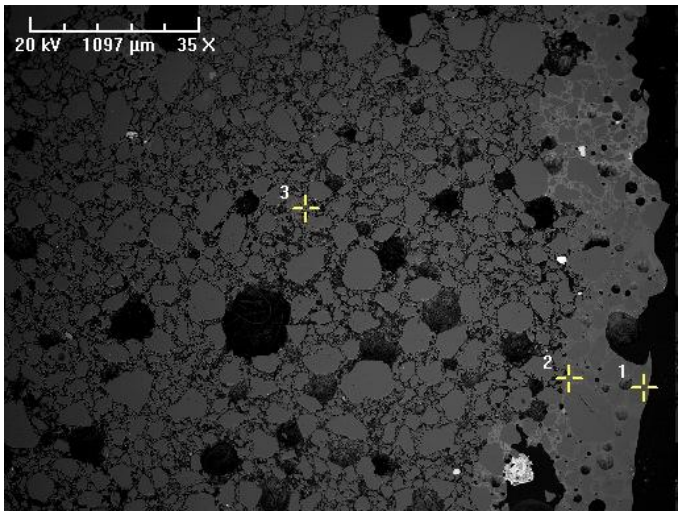


Figure L.2: Profile 2 of Batch 15, efflorescence.

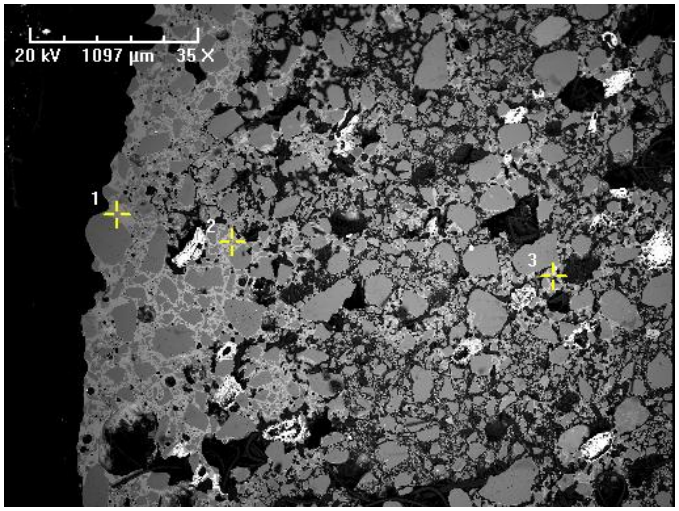


Figure L.3: Profile 1 of Batch 17, efflorescence.

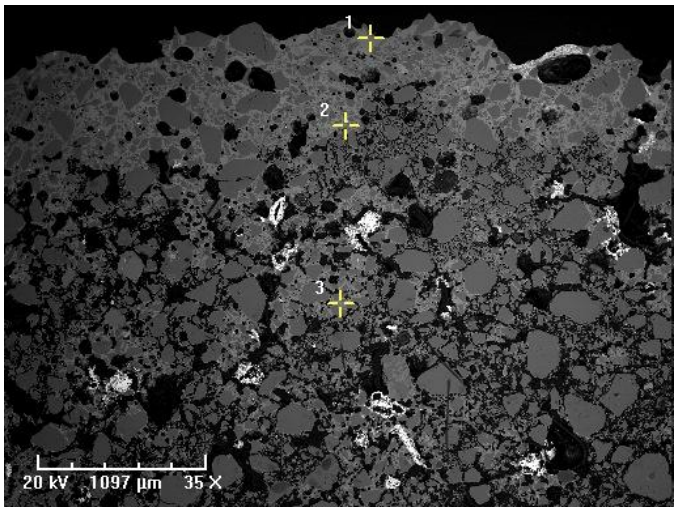


Figure L.4: Profile 2 of Batch 17, efflorescence.

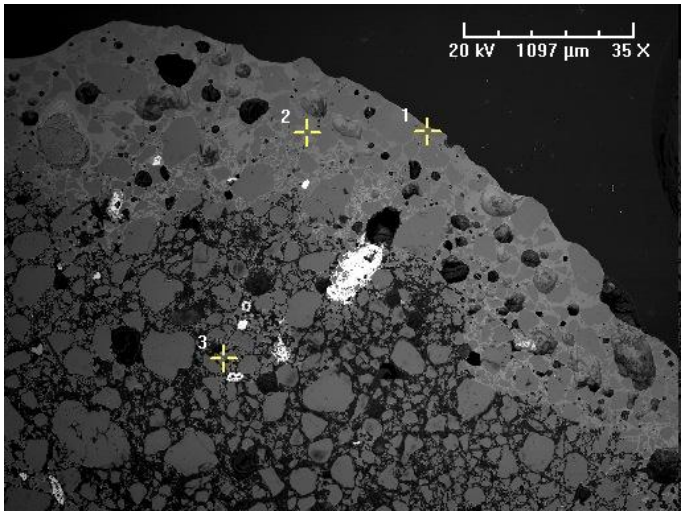


Figure L.5: Profile 1 of Batch 19, efflorescence.

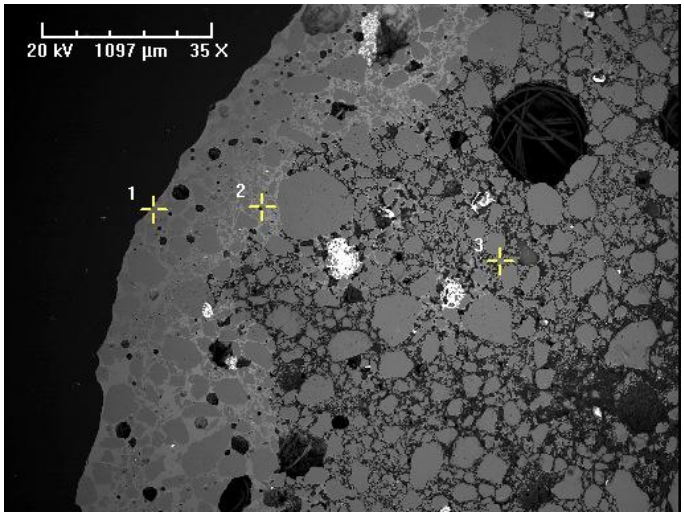


Figure L.6: Profile 2 of Batch 19, efflorescence.

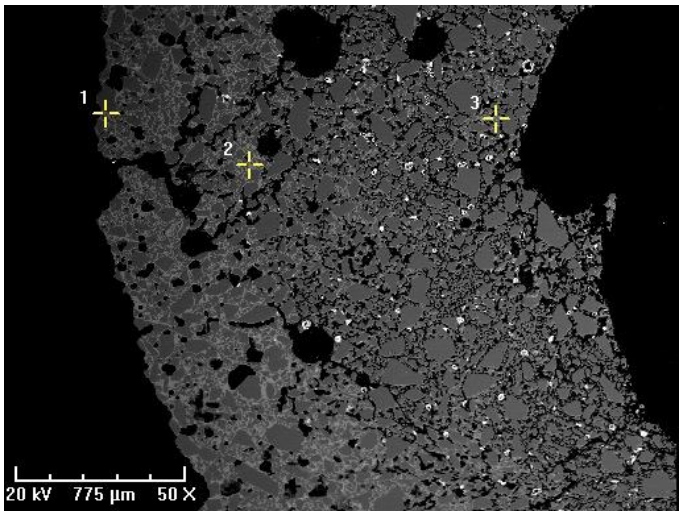


Figure L.7: Profile 1 of Batch 26, efflorescence.

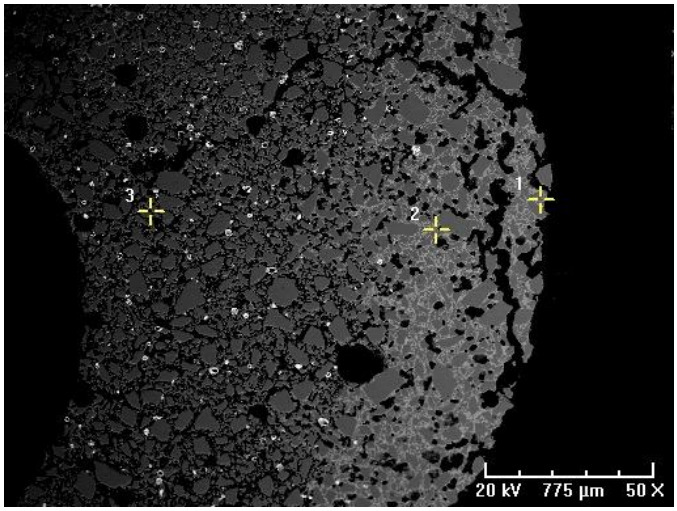


Figure L.8: Profile 2 of Batch 26, efflorescence.

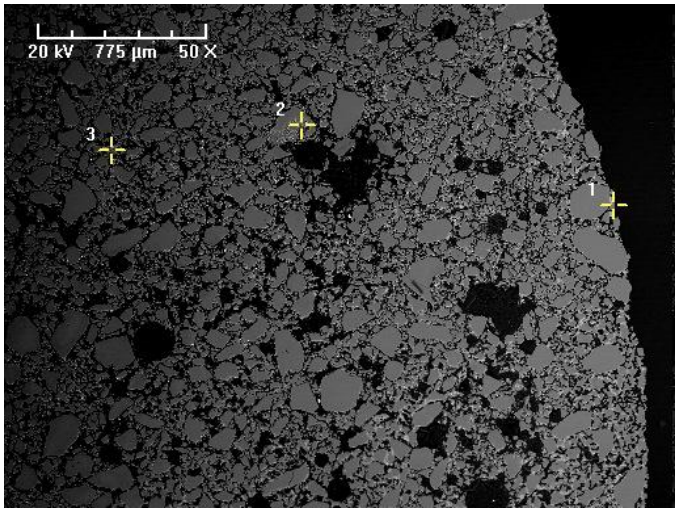


Figure L.9: Profile 1 of Batch 35, efflorescence.

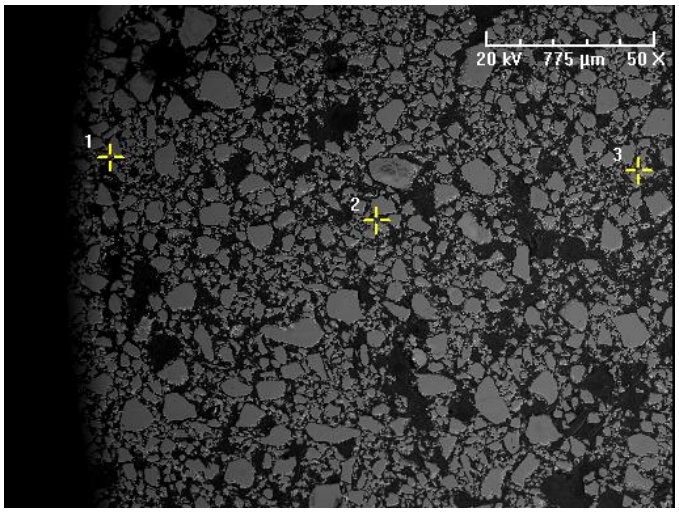


Figure L.10: Profile 2 of Batch 35, efflorescence.

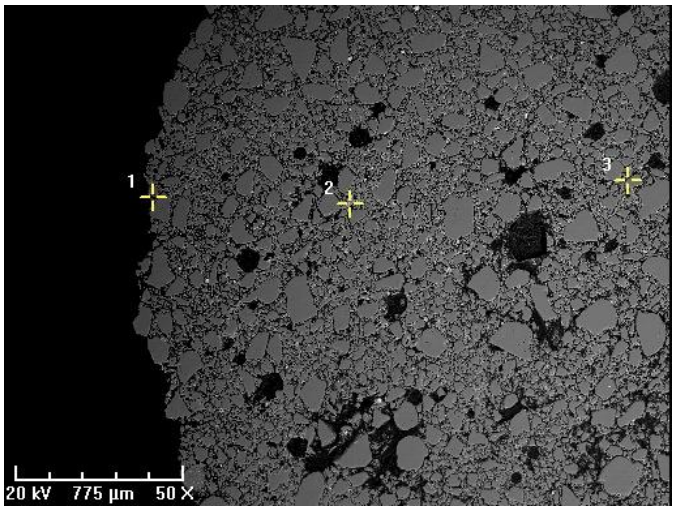


Figure L.11: Profile 1 of Batch 36, efflorescence.

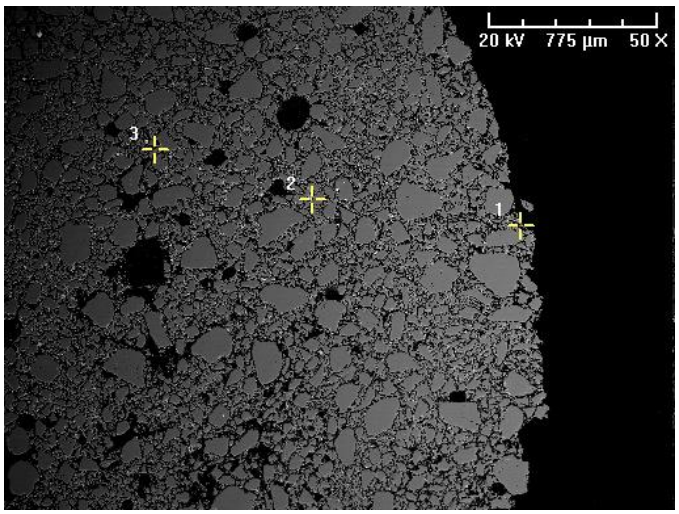


Figure L.12: Profile 2 of Batch 36, efflorescence.

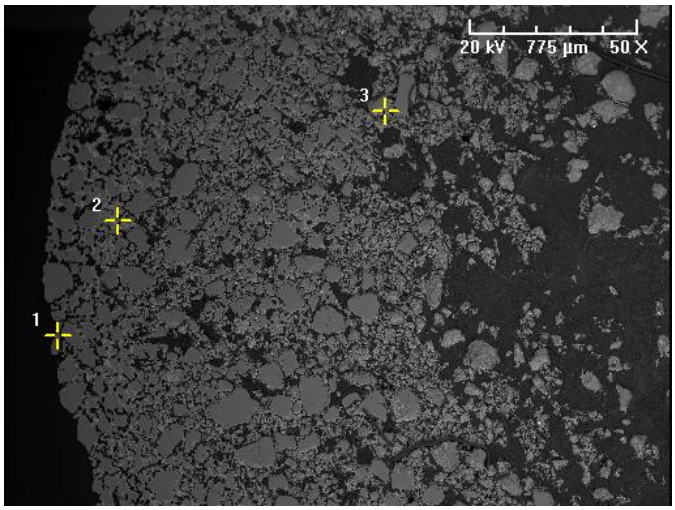


Figure L.13: Profile 1 of Batch 38, efflorescence.

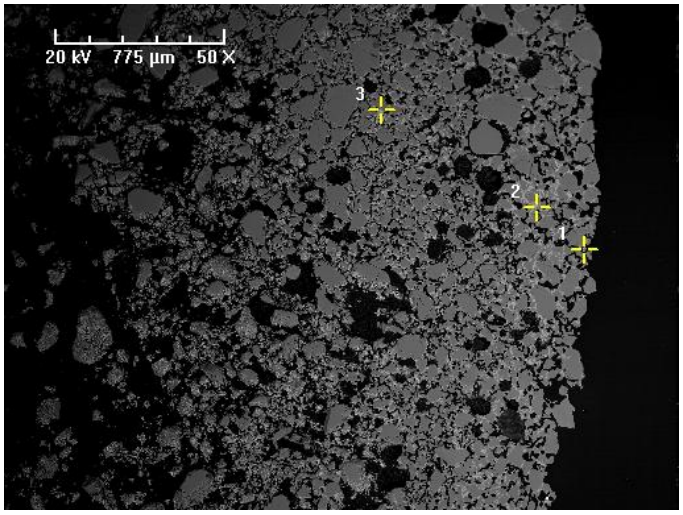


Figure L.14: Profile 2 of Batch 38, efflorescence.

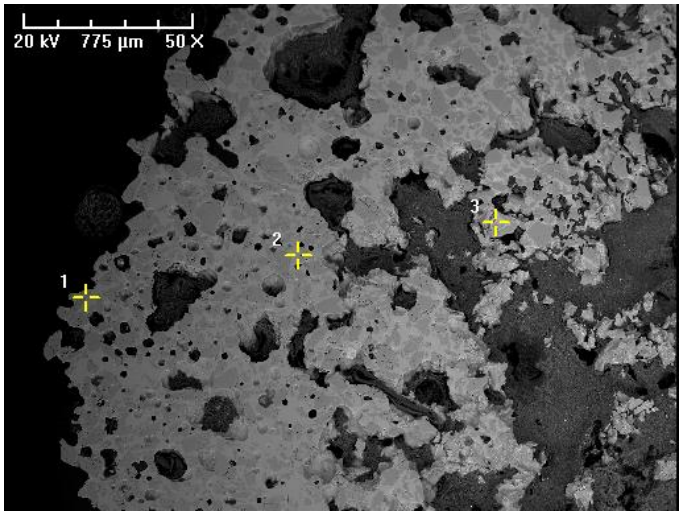


Figure L.15: Profile 1 of Batch 39, efflorescence.

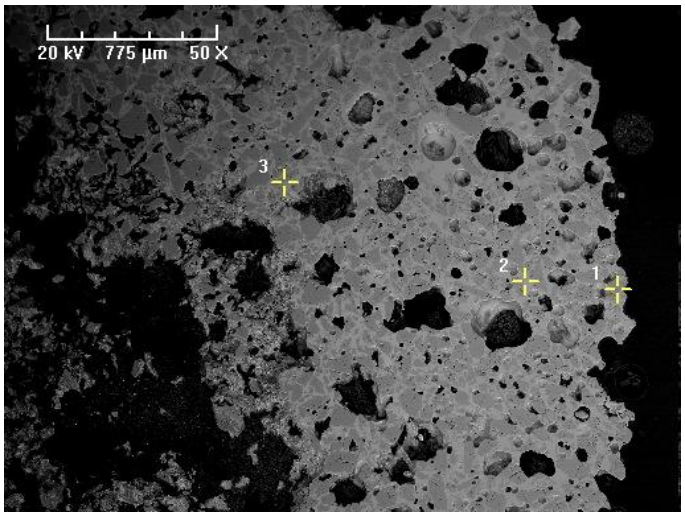


Figure L.16: Profile 2 of Batch 39, efflorescence.

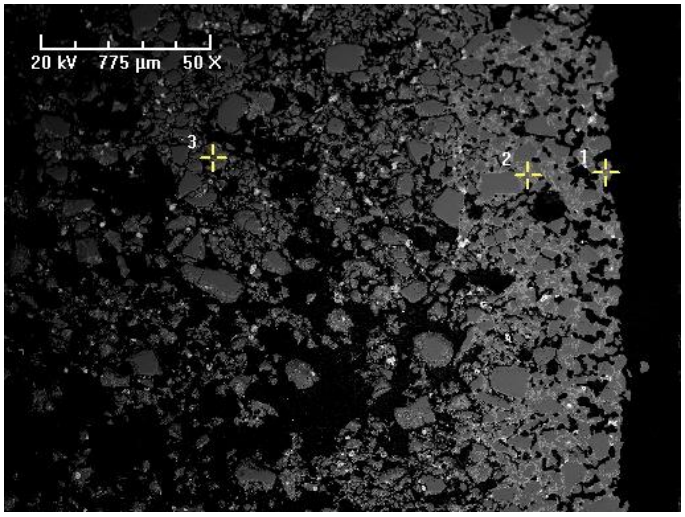


Figure L.17: Profile 1 of Batch 40, efflorescence.

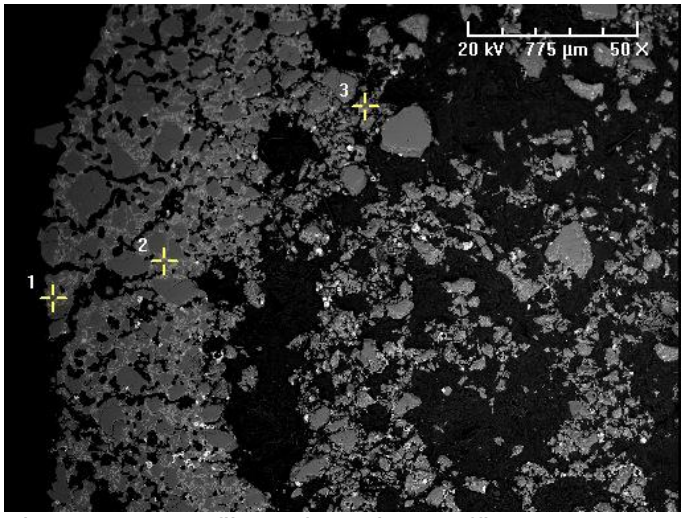


Figure L.18: Profile 2 of Batch 40, efflorescence.

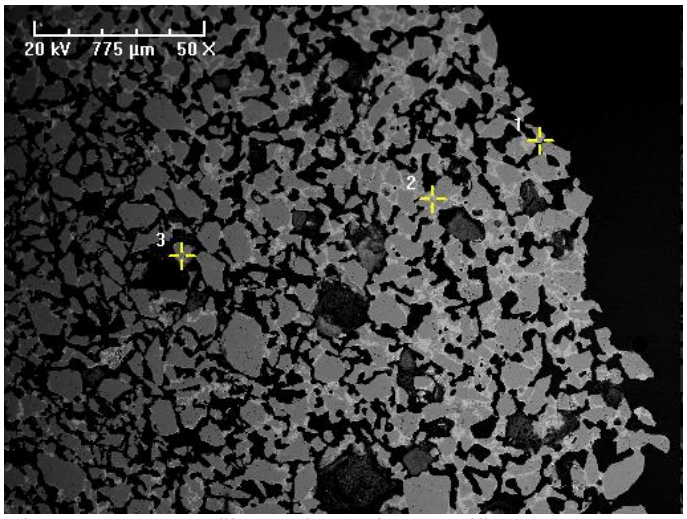


Figure L.19: Profile 1 of Batch 41, efflorescence.

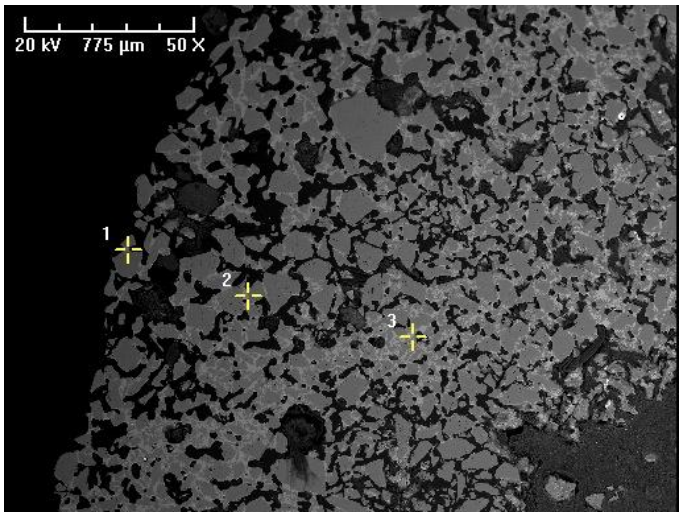


Figure L.20: Profile 2 of Batch 41, efflorescence.

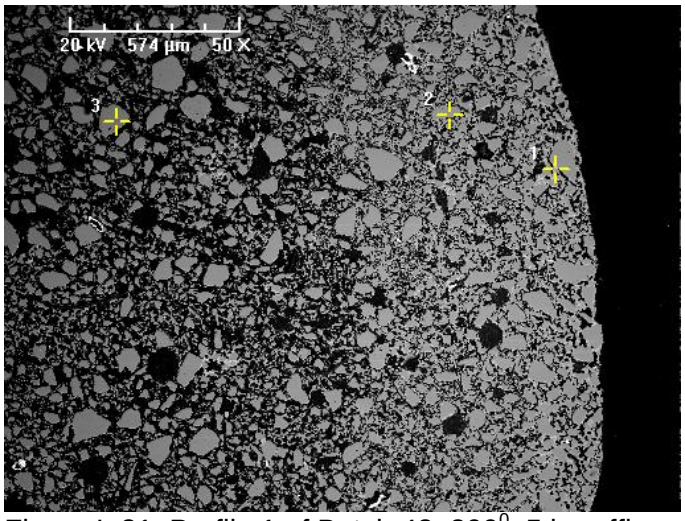


Figure L.21: Profile 1 of Batch 42, 800^{0}, 5 hr, efflorescence.

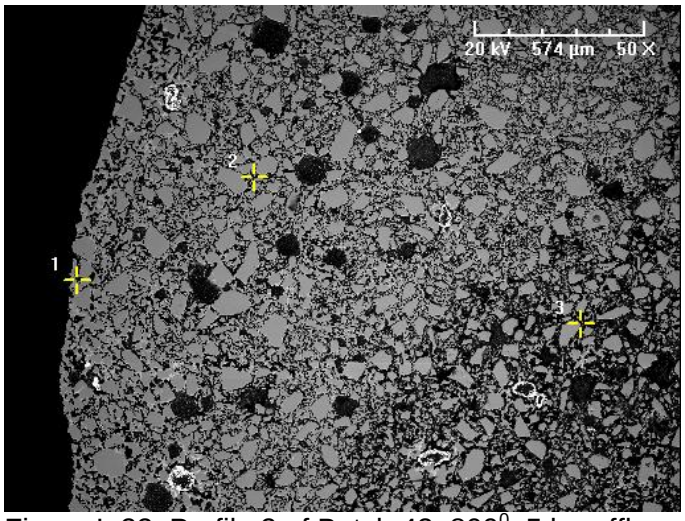


Figure L.22: Profile 2 of Batch 42, 800^0, 5 hr, efflorescence.

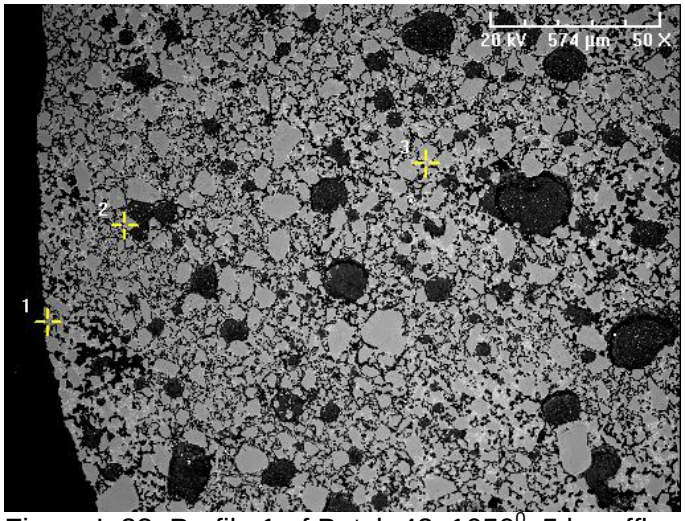


Figure L.23: Profile 1 of Batch 42, 1050^0, 5 hr, efflorescence.

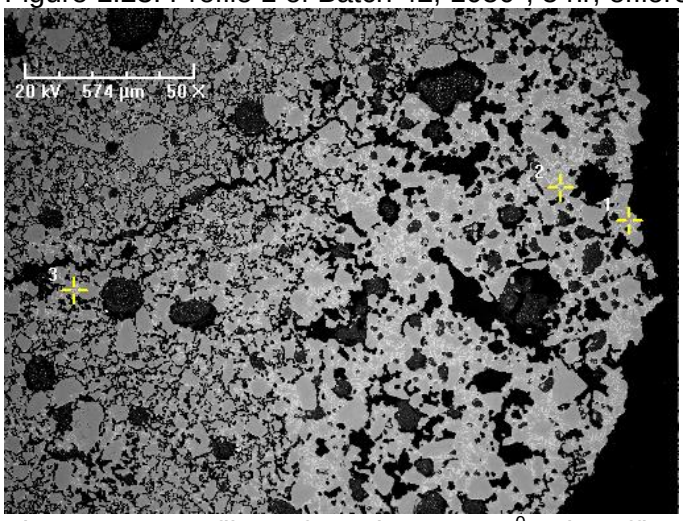


Figure L.24: Profile 2 of Batch 42, 1050^0, 5 hr, efflorescence.

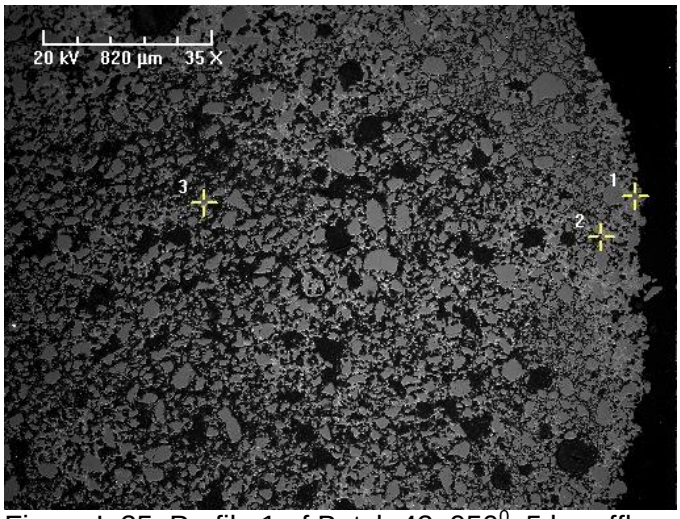


Figure L.25: Profile 1 of Batch 42, 950^0, 5 hr, efflorescence and cementation.

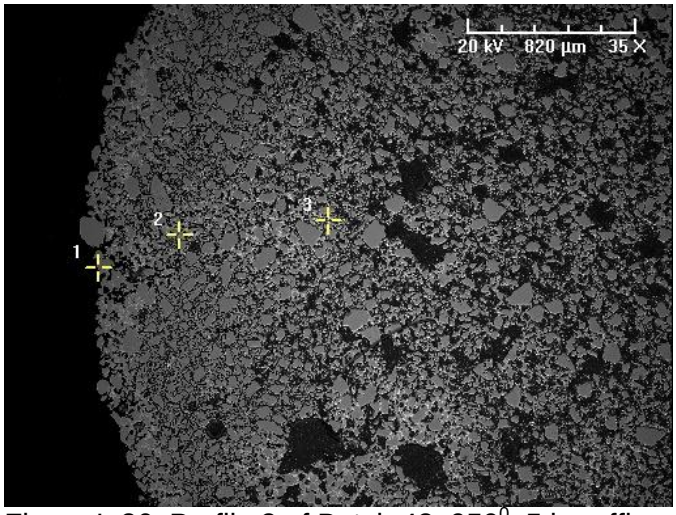


Figure L.26: Profile 2 of Batch 42, 950^0, 5 hr, efflorescence and cementation.

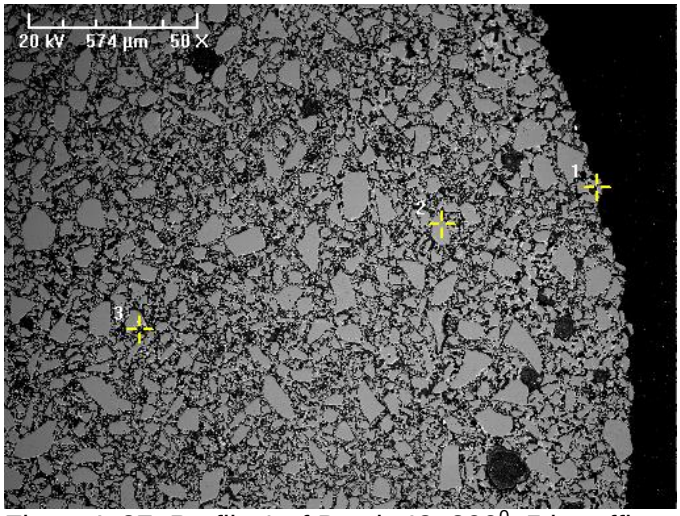


Figure L.27: Profile 1 of Batch 43, 800^0, 5 hr, efflorescence.

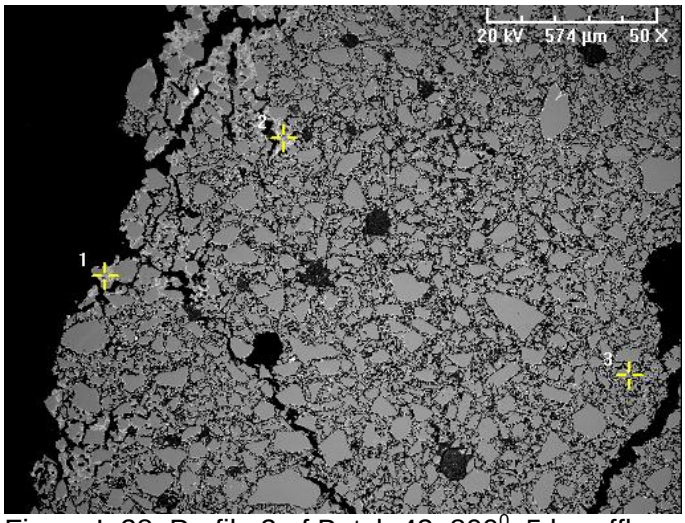


Figure L.28: Profile 2 of Batch 43, 800^0, 5 hr, efflorescence.

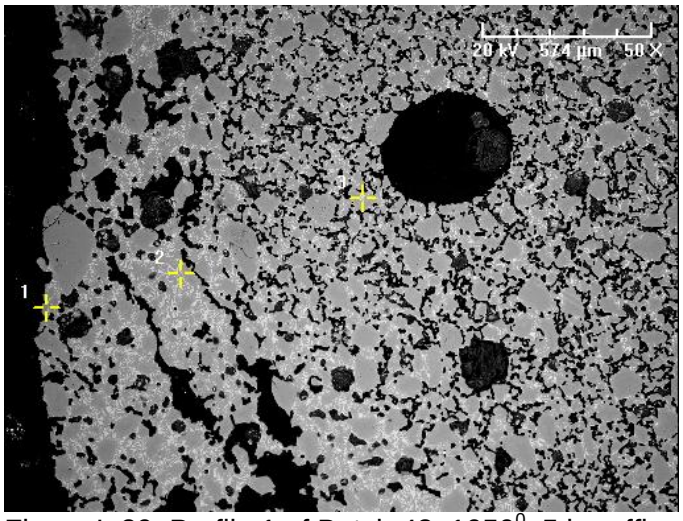


Figure L.29: Profile 1 of Batch 43, 1050^0, 5 hr, efflorescence.

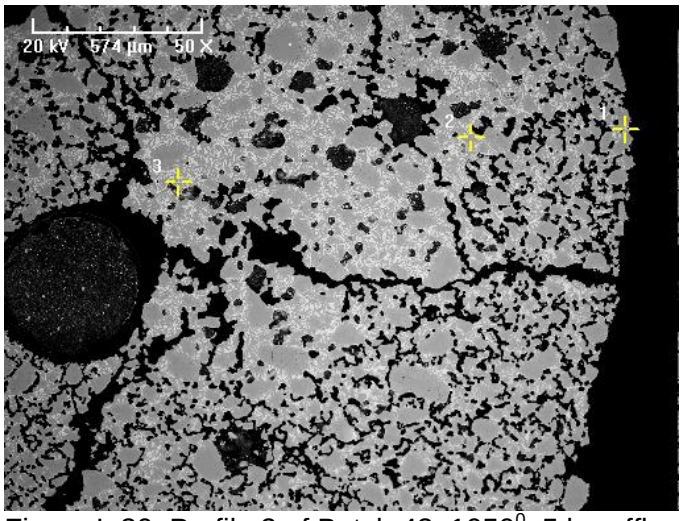


Figure L.30: Profile 2 of Batch 43, 1050^0, 5 hr, efflorescence.

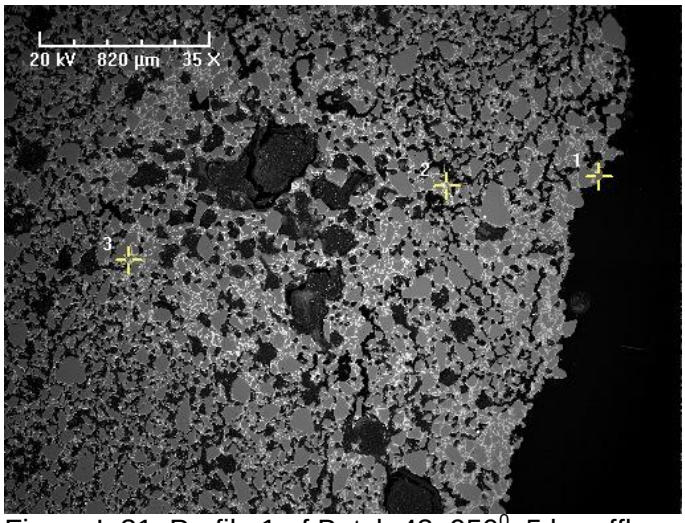


Figure L.31: Profile 1 of Batch 43, 950^0, 5 hr, efflorescence and cementation.

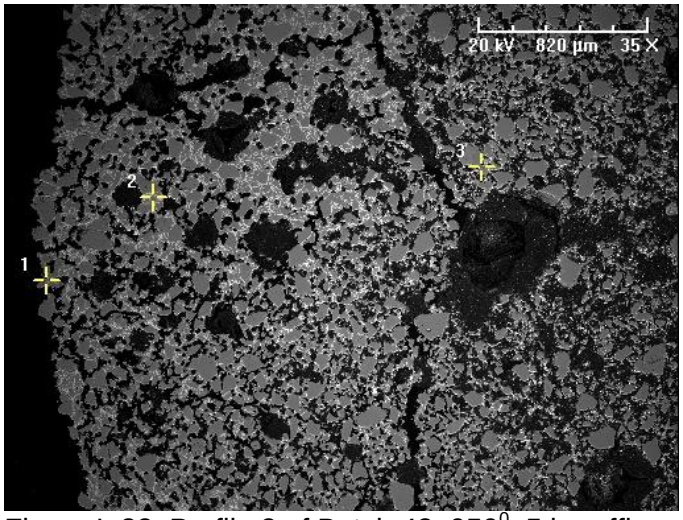


Figure L.32: Profile 2 of Batch 43, 950^0, 5 hr, efflorescence and cementation.

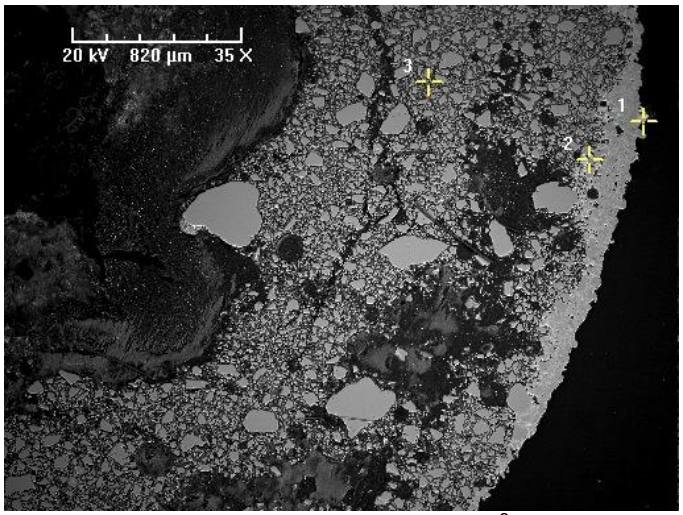


Figure L.33: Profile 1 of Batch 44, 950^0, 5 hr, cementation.

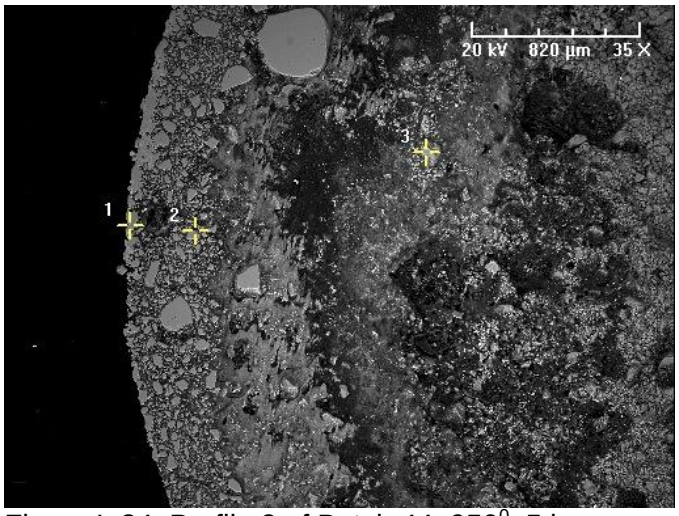


Figure L.34: Profile 2 of Batch 44, 950^0, 5 hr, cementation.

Appendix M: EDS Analysis Raw Data of Experimental Samples

BATCH	TEMP	TIME	GLAZING	PHASE	SiO_2	Al_2O_3	CaO	Na_2O	K_2O	Fe_2O_3	CuO	MgO	Cl
15	900	45 min	Efflorescence	Glaze 1	75.95	1.99	3.73	12.18	0.80	1.34	2.08	<0.63	
15	900	45 min	Efflorescence	Interparticle 1	97.67	1.00	<0.40	<0.83	0.50	<0.65	<0.85	<0.63	
15	900	45 min	Efflorescence	Core 1	95.66	1.16	<0.40	<0.83	<0.42	<0.65	<0.85	<0.63	
15	900	45 min	Efflorescence	Glaze 2	43.79	1.34	0.84	11.03	<0.42	<0.65	36.08	<0.63	6.67
15	900	45 min	Efflorescence	Interparticle 2	76.35	1.30	3.05	12.48	0.42	<0.65	3.94	<0.63	
15	900	45 min	Efflorescence	Core 2	89.80	1.29	0.67	2.10	0.45	<0.65	5.71	<0.63	
17	900	1.30 hr	Efflorescence	Glaze 1	68.71	1.37	7.25	6.32	1.25	5.09	7.70	<0.63	
17	900	1.30 hr	Efflorescence	Interparticle 1	89.45	1.20	2.27	1.61	0.72	1.09	3.44	<0.63	
17	900	1.30 hr	Efflorescence	Core 1	98.07	0.92	<0.40	<0.83	0.43	<0.65	1.30	<0.63	
17	900	1.30 hr	Efflorescence	Glaze 2	69.19	3.57	4.79	8.13	1.52	1.88	10.91	<0.63	
17	900	1.30 hr	Efflorescence	Interparticle 2	85.25	1.41	5.85	2.25	0.73	0.76	5.77	<0.63	

BATCH	TEMP	TIME	GLAZING	PHASE	SiO_2	Al_2O_3	CaO	Na_2O	K_2O	Fe_2O_3	CuO	MgO	Cl
17	900	1.30 hr	Efflorescence	Core 2	88.18	1.22	3.99	1.07	<0.42	3.64	3.63	<0.63	
19	900	1.30 hr	Efflorescence	Glaze 1	70.19	1.45	8.42	12.31	0.78	<0.65	7.78	<0.63	
19	900	1.30 hr	Efflorescence	Interparticle 1	83.16	1.47	4.84	6.57	0.53	<0.65	6.14	<0.63	
19	900	1.30 hr	Efflorescence	Core 1	97.26	0.95	<0.40	<0.83	0.45	<0.65	1.29	<0.63	
19	900	1.30 hr	Efflorescence	Glaze 2	73.71	1.03	2.92	11.32	0.65	<0.65	12.99	<0.63	
19	900	1.30 hr	Efflorescence	Interparticle 2	82.76	1.46	2.29	2.99	<0.42	<0.65	10.65	<0.63	
19	900	1.30 hr	Efflorescence	Core 2	94.55	1.23	<0.40	<0.83	<0.42	<0.65	0.87	<0.63	
26	900	45 min	Efflorescence	Glaze 1	92.01	0.56	<0.40	0.85	<0.42	<0.65	3.96	<0.63	
26	900	45 min	Efflorescence	Interparticle 1	95.52	0.57	<0.40	0.41	<0.42	<0.65	0.92	<0.63	
26	900	45 min	Efflorescence	Core 1	98.88	0.53	<0.40	<0.83	<0.42	<0.65	<0.85	<0.63	
26	900	45 min	Efflorescence	Glaze 2	89.71	0.54	1.15	2.76	<0.42	<0.65	8.25	<0.63	
26	900	45 min	Efflorescence	Interparticle 2	94.59	0.58	<0.40	0.95	<0.42	<0.65	2.77	<0.63	
26	900	45 min	Efflorescence	Core 2	98.47	0.54	<0.40	<0.83	<0.42	<0.65	2.08	<0.63	

BATCH	TEMP	TIME	GLAZING	PHASE	SiO_2	Al_2O_3	CaO	Na_2O	K_2O	Fe_2O_3	CuO	MgO	Cl
35	950	2 hr	Efflorescence	Glaze 1	93.30	0.48	<0.40	<0.83	<0.42	<0.65	1.98	<0.63	
35	950	2 hr	Efflorescence	Interparticle 1	99.35	0.31	<0.40	<0.83	<0.42	<0.65	<0.85	<0.63	
35	950	2 hr	Efflorescence	Core 1	97.52	0.46	<0.40	<0.83	<0.42	<0.65	<0.85	<0.63	
35	950	2 hr	Efflorescence	Glaze 2	70.77	0.85	8.73	<0.83	<0.42	0.71	19.59	<0.63	
35	950	2 hr	Efflorescence	Interparticle 2	99.50	0.43	<0.40	<0.83	<0.42	<0.65	<0.85	<0.63	
35	950	2 hr	Efflorescence	Core 2	98.27	0.55	<0.40	<0.83	<0.42	<0.65	<0.85	<0.63	
36	950	2 hr	Efflorescence	Glaze 1	95.20	0.61	2.60	<0.83	<0.42	0.83	1.42	<0.63	
36	950	2 hr	Efflorescence	Interparticle 1	96.58	0.68	0.53	<0.83	<0.42	<0.65	1.16	<0.63	
36	950	2 hr	Efflorescence	Core 1	98.61	0.51	<0.40	<0.83	<0.42	<0.65	<0.85	<0.63	
36	950	2 hr	Efflorescence	Glaze 2	91.11	0.52	5.21	<0.83	<0.42	1.26	1.20	<0.63	
36	950	2 hr	Efflorescence	Interparticle 2	76.63	0.32	4.90	<0.83	<0.42	7.42	5.57	0.90	
36	950	2 hr	Efflorescence	Core 2	96.17	0.39	<0.40	<0.83	<0.42	0.67	<0.85	<0.63	
38	950	5 hr	Efflorescence	Glaze 1	74.03	1.14	4.71	13.37	<0.42	0.72	5.01	<0.63	

BATCH	TEMP	TIME	GLAZING	PHASE	SiO_2	Al_2O_3	CaO	Na_2O	K_2O	Fe_2O_3	CuO	MgO	Cl
38	950	5 hr	Efflorescence	Interparticle 1	96.08	0.71	0.88	2.99	<0.42	<0.65	1.39	<0.63	
38	950	5 hr	Efflorescence	Core 1	73.99	0.75	5.38	14.18	<0.42	<0.65	5.49	<0.63	
38	950	5 hr	Efflorescence	Glaze 2	75.87	0.72	6.76	14.32	<0.42	<0.65	3.90	<0.63	
38	950	5 hr	Efflorescence	Interparticle 2	99.18	0.61	<0.40	<0.83	<0.42	<0.65	<0.85	<0.63	
38	950	5 hr	Efflorescence	Core 2	97.31	0.40	<0.40	<0.83	<0.42	<0.65	<0.85	<0.63	
39	950	5 hr	Efflorescence	Glaze 1	98.65	0.42	<0.40	<0.83	<0.42	<0.65	1.10	<0.63	
39	950	5 hr	Efflorescence	Interparticle 1	97.26	0.54	<0.40	<0.83	<0.42	<0.65	0.97	<0.63	
39	950	5 hr	Efflorescence	Core 1	98.34	0.51	<0.40	<0.83	<0.42	<0.65	<0.85	<0.63	
39	950	5 hr	Efflorescence	Glaze 2	89.49	0.59	1.40	1.80	<0.42	<0.65	5.46	<0.63	
39	950	5 hr	Efflorescence	Interparticle 2	93.86	0.34	1.56	1.44	<0.42	<0.65	5.34	<0.63	
39	950	5 hr	Efflorescence	Core 2	98.21	0.51	<0.40	<0.83	0.42	<0.65	<0.85	<0.63	
40	950	5 hr	Efflorescence	Glaze 1	92.37	0.56	<0.40	<0.83	<0.42	<0.65	5.32	<0.63	
40	950	5 hr	Efflorescence	Interparticle 1	94.99	0.58	<0.40	<0.83	<0.42	<0.65	5.78	<0.63	

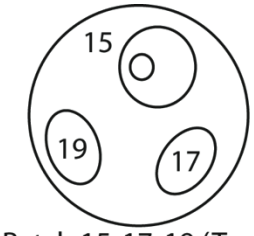
BATCH	TEMP	TIME	GLAZING	PHASE	SiO_2	Al_2O_3	CaO	Na_2O	K_2O	Fe_2O_3	CuO	MgO	Cl
40	950	5 hr	Efflorescence	Core 1	93.04	0.50	<0.40	<0.83	<0.42	<0.65	4.84	<0.63	
40	950	5 hr	Efflorescence	Glaze 2	97.11	0.43	<0.40	<0.83	<0.42	<0.65	1.08	<0.63	
40	950	5 hr	Efflorescence	Interparticle 2	95.98	0.69	<0.40	<0.83	<0.42	<0.65	4.11	<0.63	
40	950	5 hr	Efflorescence	Core 2	97.68	0.31	<0.40	<0.83	<0.42	<0.65	3.18	<0.63	
41	950	5 hr	Efflorescence	Glaze 1	89.64	0.59	<0.40	2.16	<0.42	<0.65	4.16	<0.63	
41	950	5 hr	Efflorescence	Interparticle 1	95.04	0.50	<0.40	<0.83	<0.42	<0.65	0.91	<0.63	
41	950	5 hr	Efflorescence	Core 1	98.96	0.57	<0.40	<0.83	<0.42	<0.65	<0.85	<0.63	
41	950	5 hr	Efflorescence	Glaze 2	96.73	0.56	<0.40	0.85	<0.42	<0.65	2.08	<0.63	
41	950	5 hr	Efflorescence	Interparticle 2	96.56	0.62	<0.40	<0.83	<0.42	<0.65	<0.85	<0.63	
41	950	5 hr	Efflorescence	Core 2	97.84	0.56	<0.40	<0.83	<0.42	<0.65	<0.85	<0.63	
42	800	5 hr	Efflorescence	Glaze 1	85.07	0.65	6.70	2.38	<0.42	<0.65	2.27	<0.63	
42	800	5 hr	Efflorescence	Interparticle 1	98.02	0.49	0.50	0.88	<0.42	<0.65	1.58	<0.63	
42	800	5 hr	Efflorescence	Core 1	86.27	0.43	6.47	2.67	<0.42	<0.65	1.61	<0.63	

BATCH	TEMP	TIME	GLAZING	PHASE	SiO_2	Al_2O_3	CaO	Na_2O	K_2O	Fe_2O_3	CuO	MgO	Cl
42	800	5 hr	Efflorescence	Glaze 2	100.88	0.65	<0.40	<0.83	<0.42	<0.65	<0.85	<0.63	
42	800	5 hr	Efflorescence	Interparticle 2	97.01	0.40	<0.40	<0.83	<0.42	<0.65	<0.85	<0.63	
42	800	5 hr	Efflorescence	Core 2	96.03	0.43	<0.40	<0.83	<0.42	<0.65	<0.85	<0.63	
43	800	5 hr	Efflorescence	Glaze 1	86.06	0.43	1.57	4.83	<0.42	<0.65	6.11	<0.63	
43	800	5 hr	Efflorescence	Interparticle 1	99.66	0.61	<0.40	<0.83	<0.42	<0.65	<0.85	<0.63	
43	800	5 hr	Efflorescence	Core 1	96.71	0.59	<0.40	<0.83	<0.42	<0.65	1.00	<0.63	
43	800	5 hr	Efflorescence	Glaze 2	96.28	0.65	<0.40	<0.83	<0.42	<0.65	2.77	<0.63	
43	800	5 hr	Efflorescence	Interparticle 2	93.53	0.38	<0.40	<0.83	<0.42	<0.65	5.39	<0.63	
43	800	5 hr	Efflorescence	Core 2	100.15	0.61	<0.40	<0.83	<0.42	<0.65	<0.85	<0.63	
42	1050	5 hr	Efflorescence	Glaze 1	95.80	0.58	0.66	1.14	<0.42	<0.65	1.62	<0.63	
42	1050	5 hr	Efflorescence	Interparticle 1	98.31	0.54	0.43	0.93	<0.42	<0.65	1.66	<0.63	
42	1050	5 hr	Efflorescence	Core 1	89.28	1.00	2.81	3.07	<0.42	<0.65	3.51	<0.63	
42	1050	5 hr	Efflorescence	Glaze 2	91.86	0.61	2.98	2.47	<0.42	<0.65	3.00	<0.63	

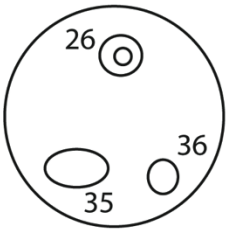
BATCH	TEMP	TIME	GLAZING	PHASE	SiO_2	Al_2O_3	CaO	Na_2O	K_2O	Fe_2O_3	CuO	MgO	Cl
42	1050	5 hr	Efflorescence	Interparticle 2	95.36	0.60	0.64	<0.83	<0.42	<0.65	1.35	<0.63	
42	1050	5 hr	Efflorescence	Core 2	96.61	0.58	1.27	1.50	<0.42	<0.65	2.04	<0.63	
43	1050	5 hr	Efflorescence	Glaze 1	91.07	0.54	0.49	1.64	<0.42	<0.65	3.21	<0.63	
43	1050	5 hr	Efflorescence	Interparticle 1	84.20	0.64	2.36	4.58	<0.42	<0.65	8.74	<0.63	
43	1050	5 hr	Efflorescence	Core 1	97.60	0.70	<0.40	<0.83	<0.42	<0.65	1.01	<0.63	
43	1050	5 hr	Efflorescence	Glaze 2	92.48	0.69	0.48	0.87	<0.42	<0.65	2.70	<0.63	
43	1050	5 hr	Efflorescence	Interparticle 2	99.13	0.55	<0.40	<0.83	<0.42	<0.65	1.08	<0.63	
43	1050	5 hr	Efflorescence	Core 2	99.67	0.61	<0.40	<0.83	<0.42	<0.65	<0.85	<0.63	
42	950	5 hr	Cementation	Glaze 1	93.01	0.62	0.86	<0.83	<0.42	<0.65	3.73	<0.63	
42	950	5 hr	Cementation	Interparticle 1	86.95	0.84	3.34	2.57	<0.42	<0.65	5.65	<0.63	
42	950	5 hr	Cementation	Core 1	94.51	0.65	<0.40	<0.83	<0.42	<0.65	2.17	<0.63	
42	950	5 hr	Cementation	Glaze 2	90.82	0.44	2.32	1.50	<0.42	<0.65	5.57	<0.63	
42	950	5 hr	Cementation	Interparticle 2	88.45	0.90	1.52	1.23	<0.42	0.70	5.99	<0.63	

BATCH	TEMP	TIME	GLAZING	PHASE	SiO_2	Al_2O_3	CaO	Na_2O	K_2O	Fe_2O_3	CuO	MgO	Cl
42	950	5 hr	Cementation	Core 2	94.03	0.68	0.52	0.91	<0.42	<0.65	4.27	<0.63	
43	950	5 hr	Cementation	Glaze 1	92.46	0.66	0.98	<0.83	<0.42	<0.65	7.33	<0.63	
43	950	5 hr	Cementation	Interparticle 1	95.14	0.60	<0.40	<0.83	<0.42	<0.65	2.02	<0.63	
43	950	5 hr	Cementation	Core 1	90.86	0.65	0.83	<0.83	<0.42	0.67	6.28	<0.63	
43	950	5 hr	Cementation	Glaze 2	98.26	0.43	<0.40	<0.83	<0.42	<0.65	2.18	<0.63	
43	950	5 hr	Cementation	Interparticle 2	97.26	0.55	<0.40	<0.83	<0.42	<0.65	2.91	<0.63	
43	950	5 hr	Cementation	Core 2	94.39	0.60	<0.40	<0.83	<0.42	<0.65	1.74	<0.63	
44	950	5 hr	Cementation	Glaze 1	94.55	0.58	<0.40	<0.83	<0.42	<0.65	1.40	<0.63	
44	950	5 hr	Cementation	Interparticle 1	96.40	0.67	<0.40	<0.83	<0.42	<0.65	0.90	<0.63	
44	950	5 hr	Cementation	Core 1	100.09	0.56	<0.40	<0.83	<0.42	<0.65	0.99	<0.63	
44	950	5 hr	Cementation	Glaze 2	89.54	1.37	2.68	3.70	<0.42	<0.65	2.13	<0.63	
44	950	5 hr	Cementation	Interparticle 2	95.21	1.12	2.01	1.69	<0.42	<0.65	1.30	<0.63	
44	950	5 hr	Cementation	Core 2	95.31	0.64	<0.40	<0.83	<0.42	<0.65	<0.85	<0.63	

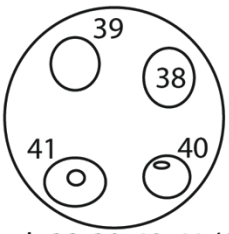
Appendix N: Experimental Bead Sample Blocks



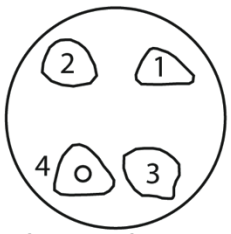
Batch 15, 17, 19 (Test)



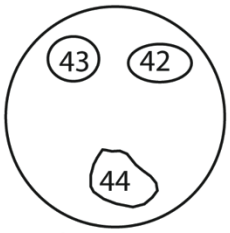
Batch 26, 35, 36 (Copper)



Batch 38, 39, 40, 41 (Glaze)



Batch 42 and 43 (Mohs)



Batch 42, 43, 44 (C)

Note:

- Block for Batch 38, 39, 40, and 41 were all fired at 950^0 C for 5 hours.
- Block for Batch 42 and 43: 1) is Batch 42 bead fired at 800^0 for 5 hours, 2) is Batch 43 fired at 800^0 for 5 hours, 3) is Batch 42 fired at 1050^0 for 5 hours and 4) Batch 43 1050^0 for 5 hours.
- Block 42, 43, and 44 were all subjected to Cementation glazing. 42 and 43 were also glazed by Efflorescence

Appendix O: Particle Size SEM Images

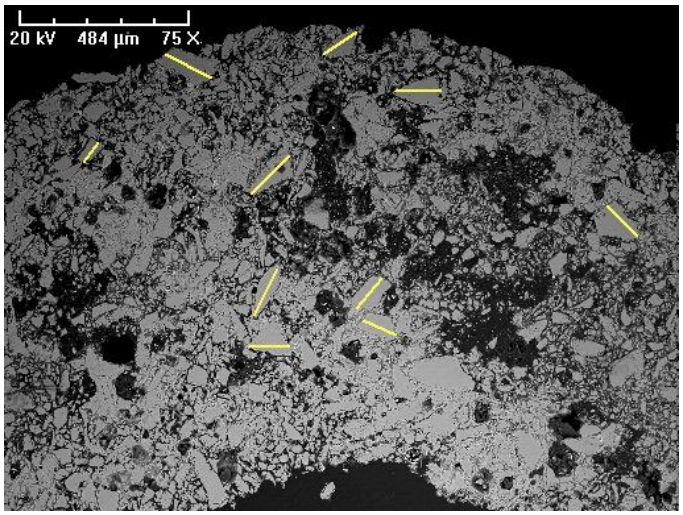


Figure O.1: Profile 1 of bead 54.00.75-1.

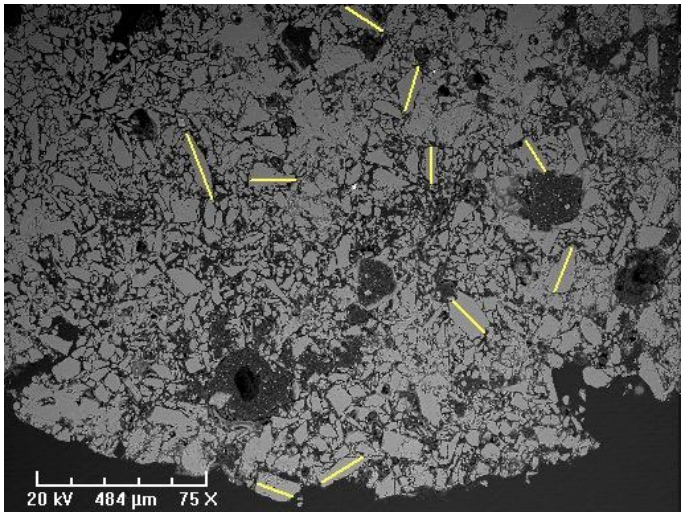


Figure O.2: Profile 2 of bead 54.00.75-1.

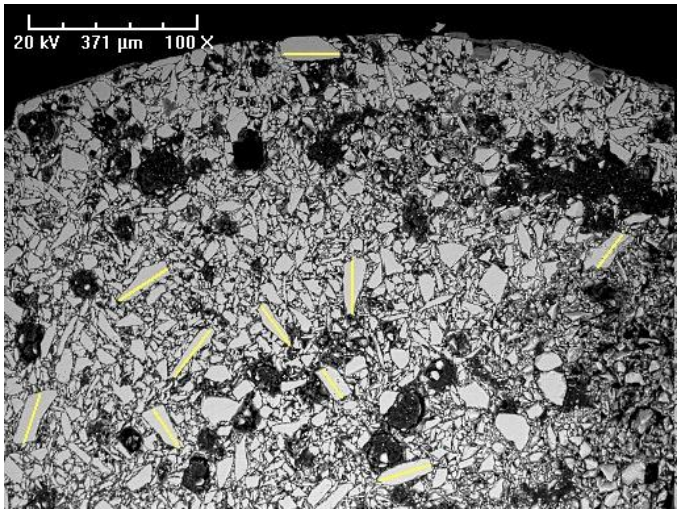


Figure O.3: Profile 1 of bead 54.00.75-2.

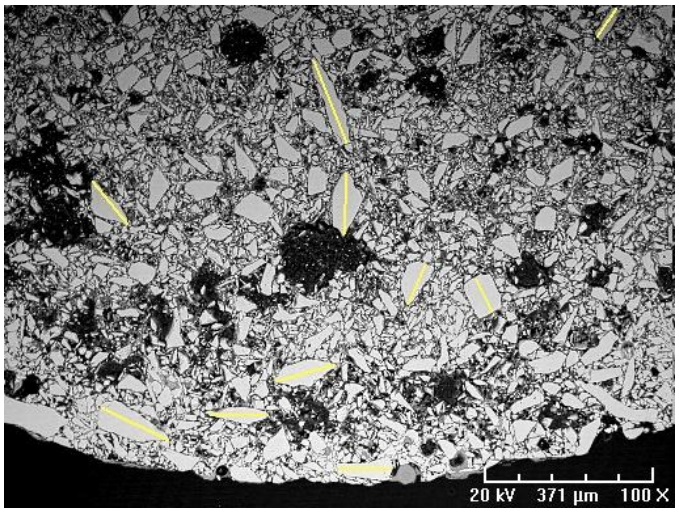


Figure O.4: Profile 2 of bead 54.00.75-2.

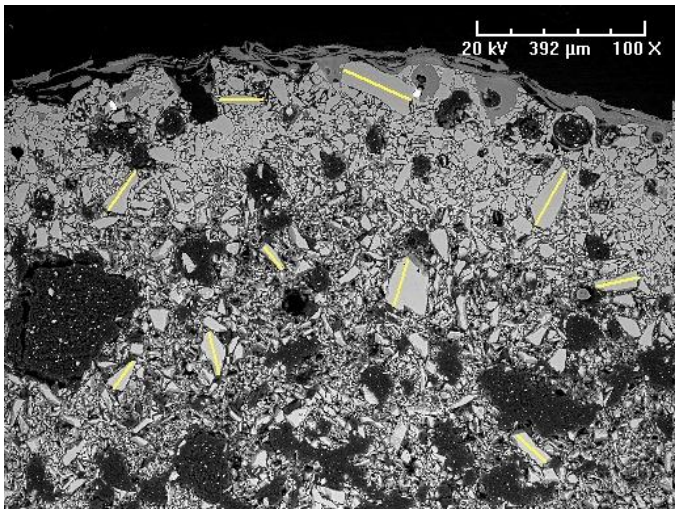


Figure O.5: Profile 1 of bead 54.00.75-3.

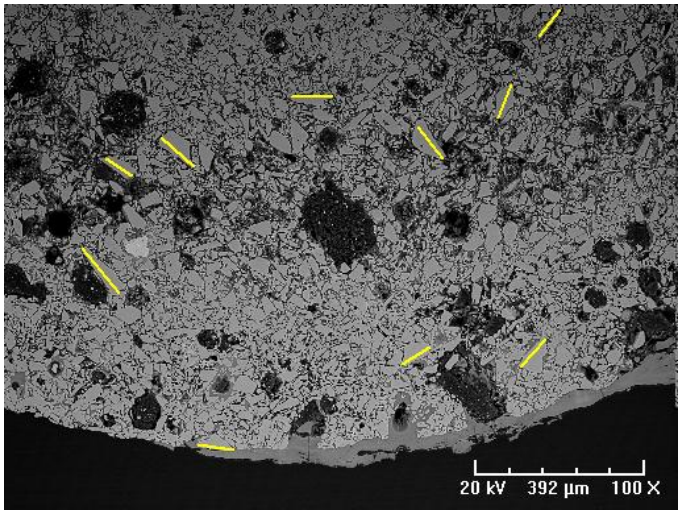


Figure O.6: Profile 2 of bead 54.00.75-3.

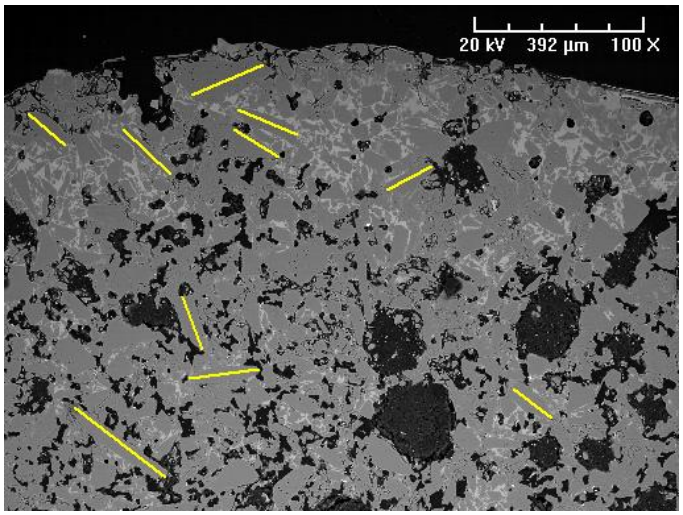


Figure O.7: Profile 1 of bead 54.00.75-4.

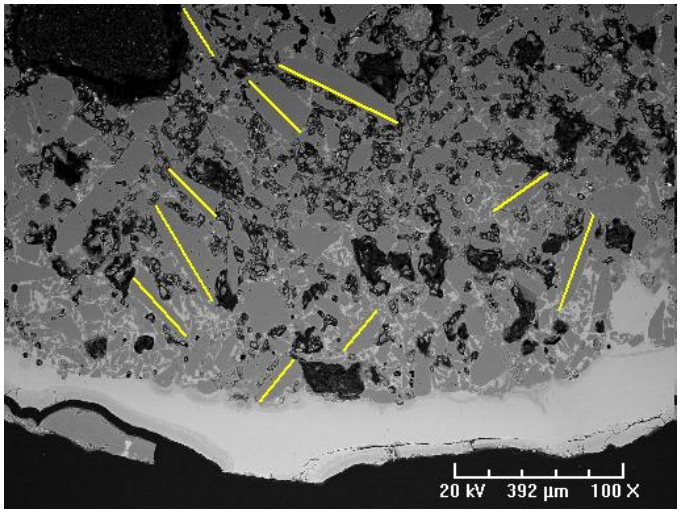


Figure O.8: Profile 2 of bead 54.00.75-4.

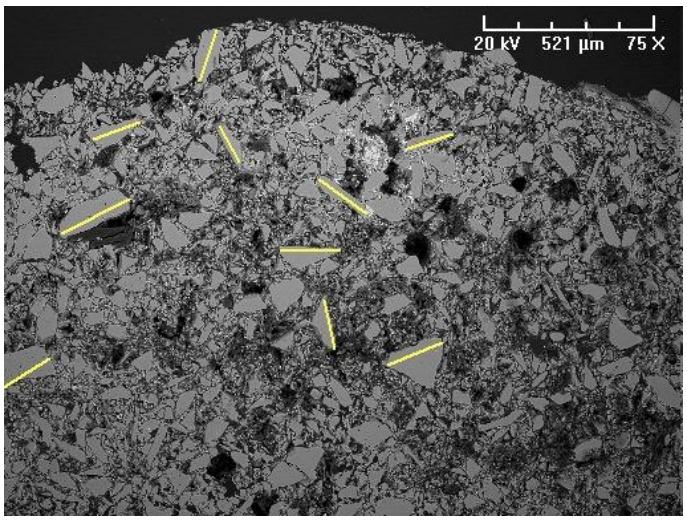


Figure O.9: Profile 1 of bead 54.00.75-5.

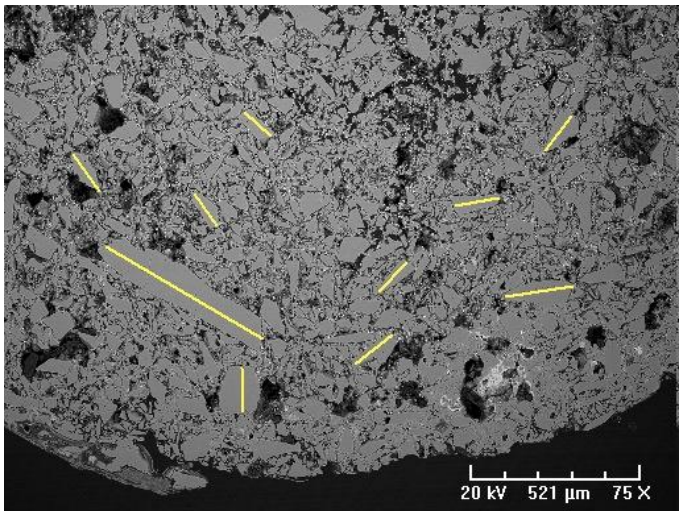


Figure O.10: Profile 2 of bead 54.00.75-5.

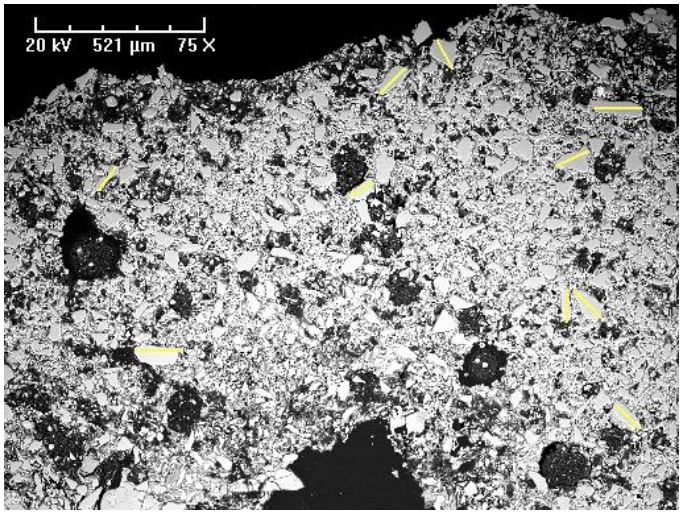


Figure O.11: Profile 1 of bead 54.00.75-6.

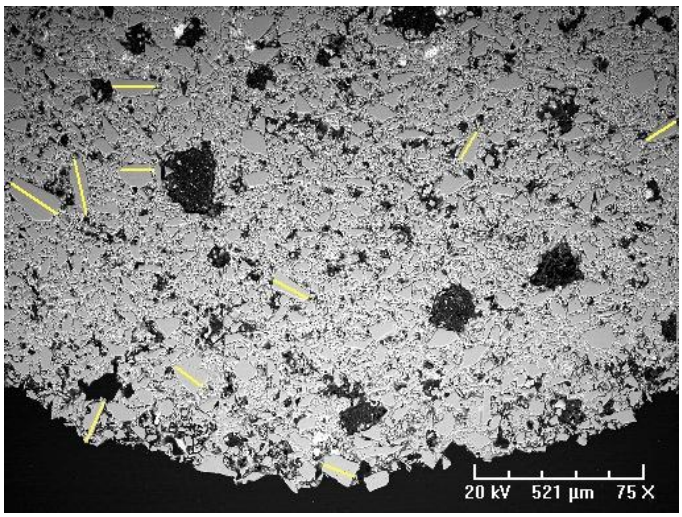


Figure O.12: Profile 2 of bead 54.00.75-6.

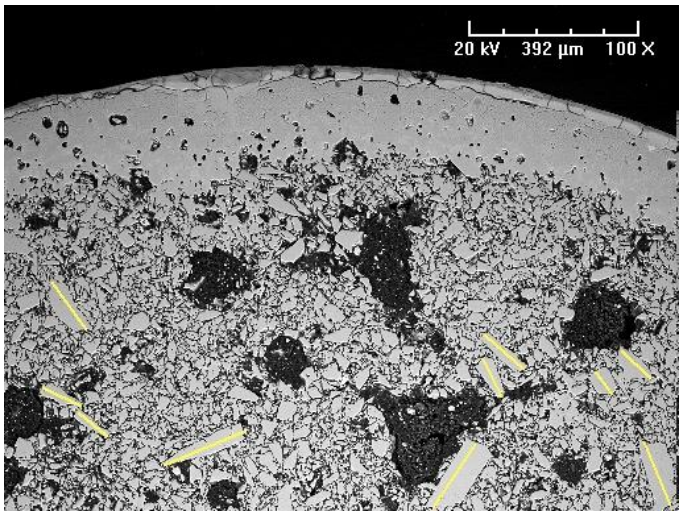


Figure O.13: Profile 1 of bead 54.00.75-7.

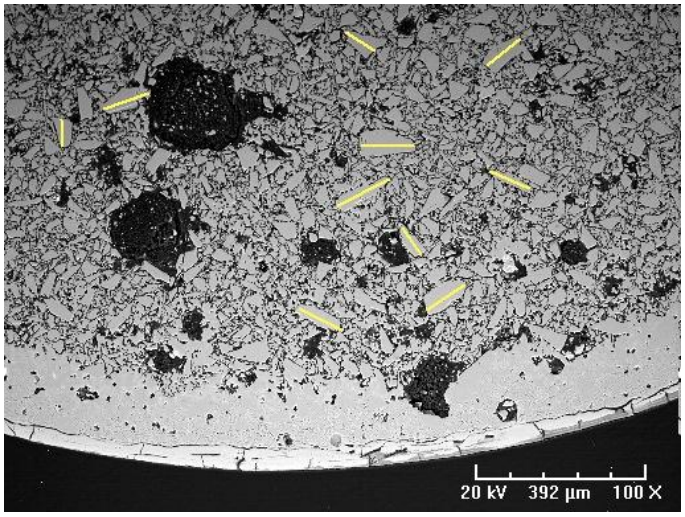


Figure O.14: Profile 2 of bead 54.00.75-7.

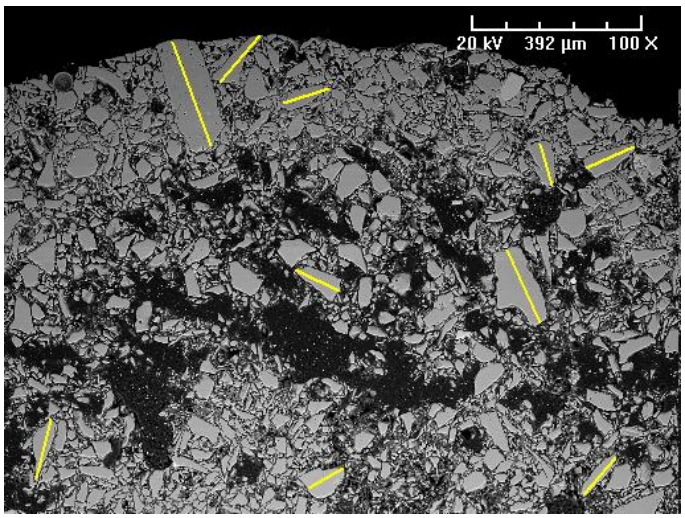


Figure O.15: Profile 1 of bead 54.00.75-8.

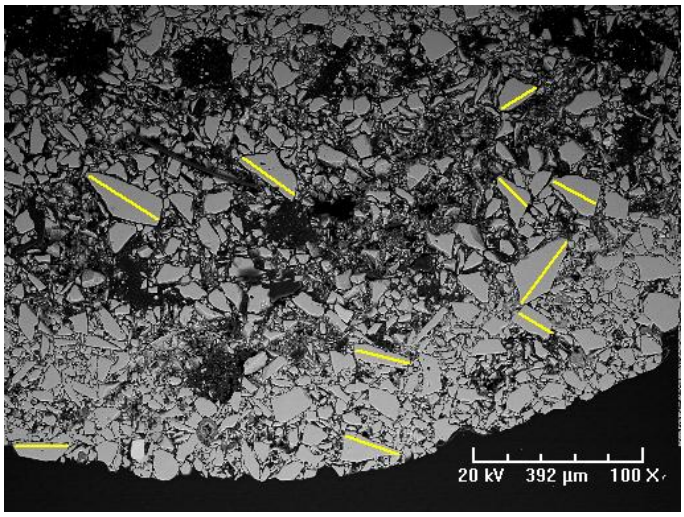


Figure O.16: Profile 2 of bead 54.00.75-8.

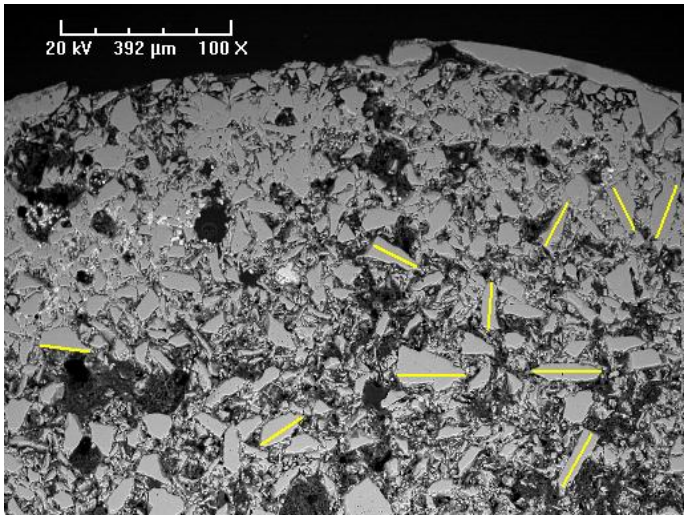


Figure O.17: Profile 1 of bead 54.00.75-9.

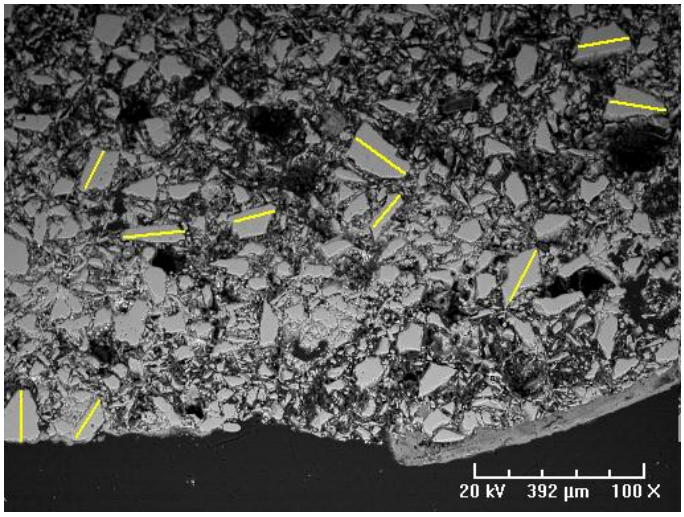


Figure O.18: Profile 2 of bead 54.00.75-9.

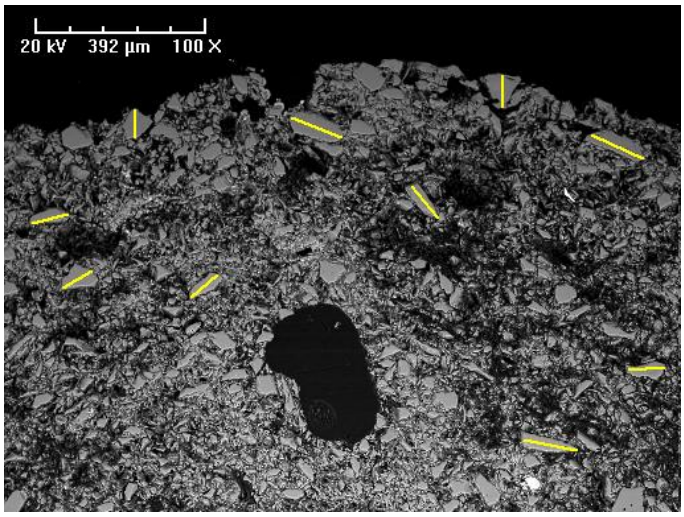


Figure O.19: Profile 1 of bead 54.00.75-10.

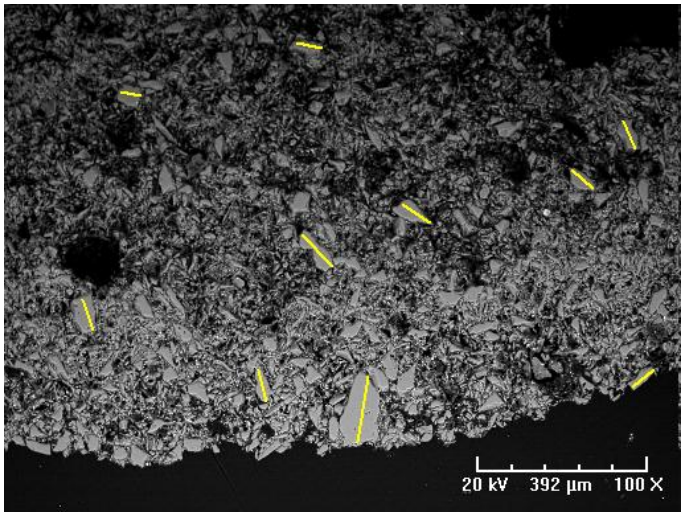


Figure O.20: Profile 2 of bead 54.00.75-10.

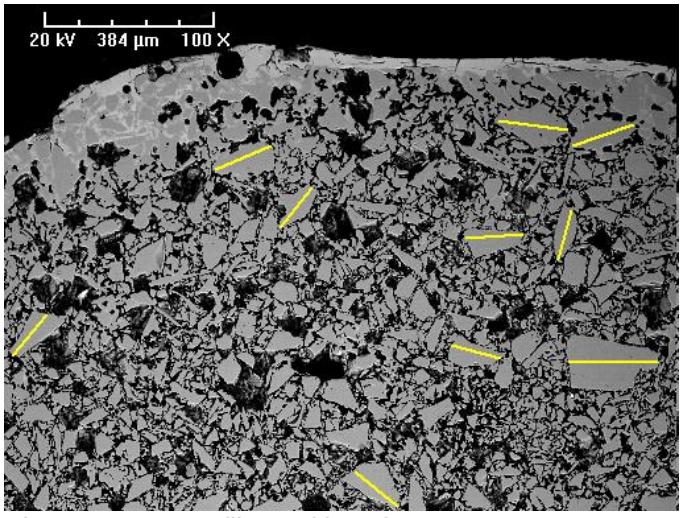


Figure O.21: Profile 1 of bead 2379-1.

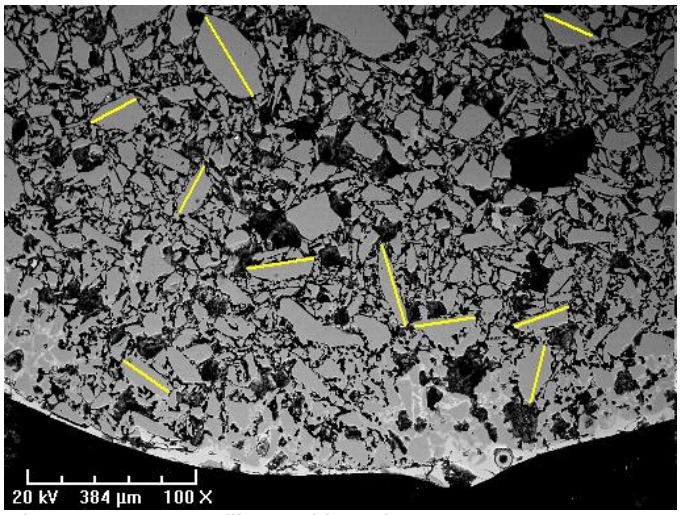


Figure O.22: Profile 2 of bead 2379-1.

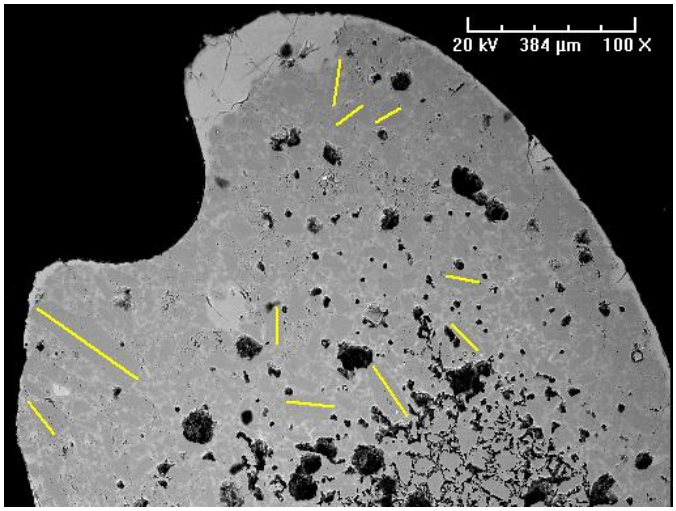


Figure O.23: Profile 1 of bead 2379-2.

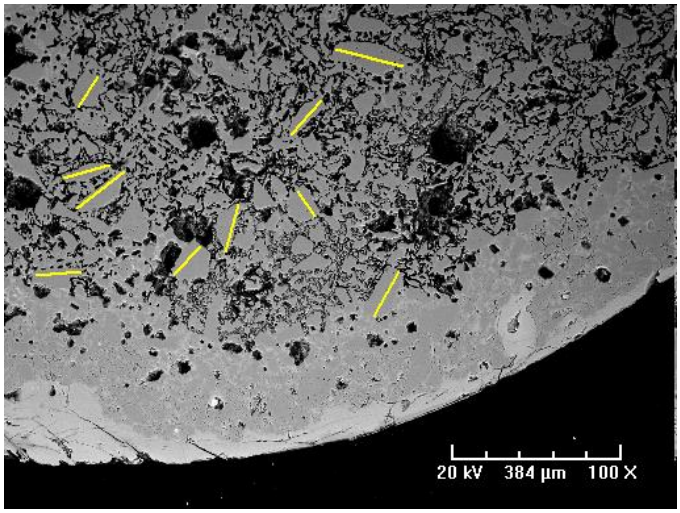


Figure O.24: Profile 2 of bead 2379-2.

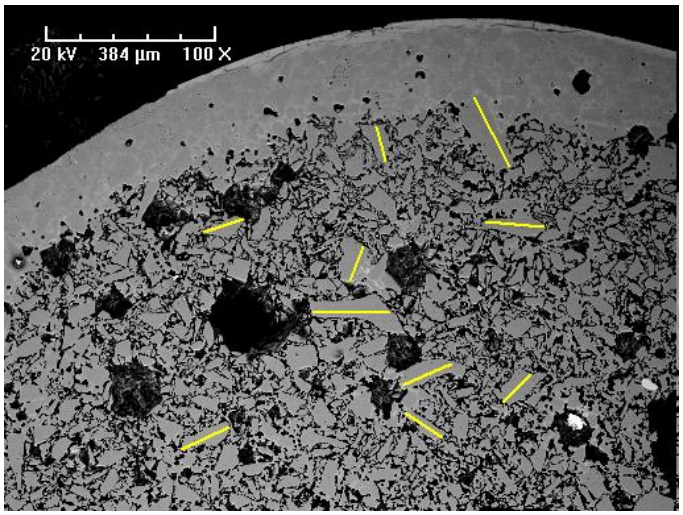


Figure O.25: Profile 1 of bead 2379-3.

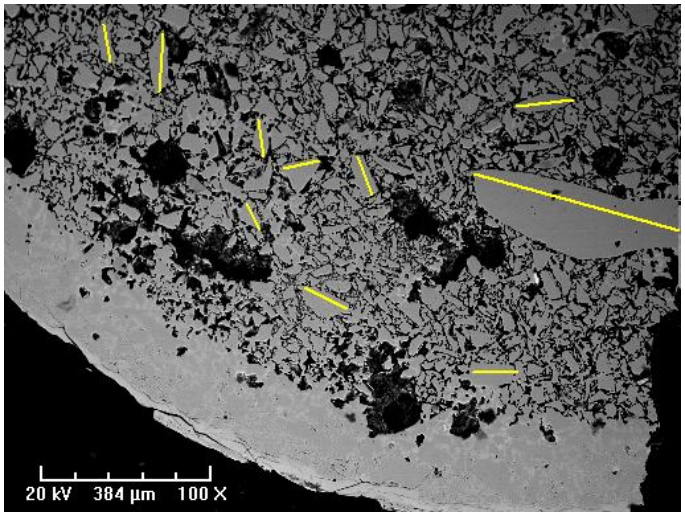


Figure O.26: Profile 2 of bead 2379-3.

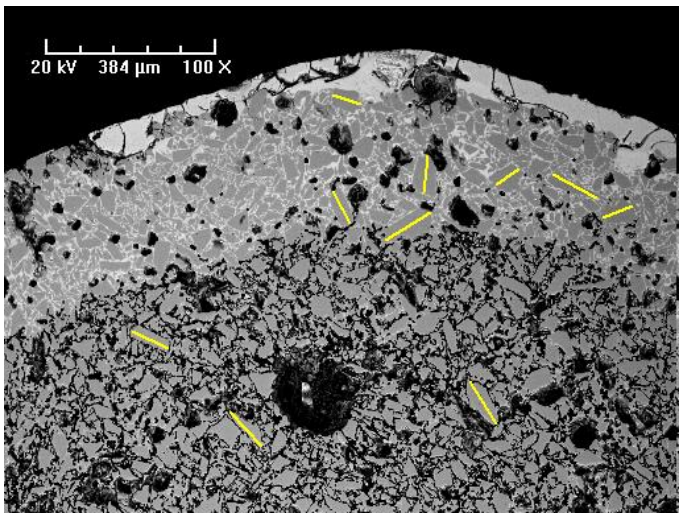


Figure O.27: Profile 1 of bead 2379-4.

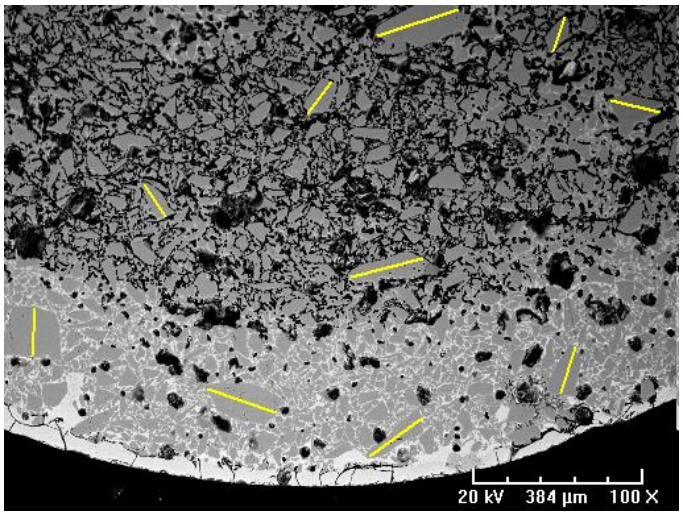


Figure O.28: Profile 2 of bead 2379-4.

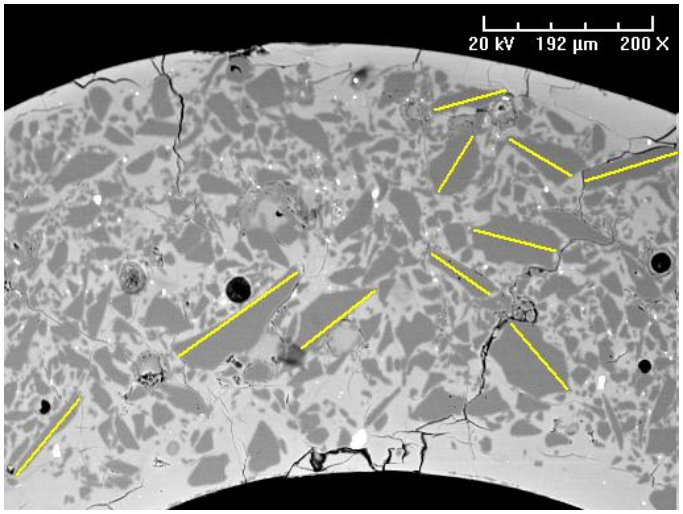


Figure O.29: Profile 1 of bead 2379-5.

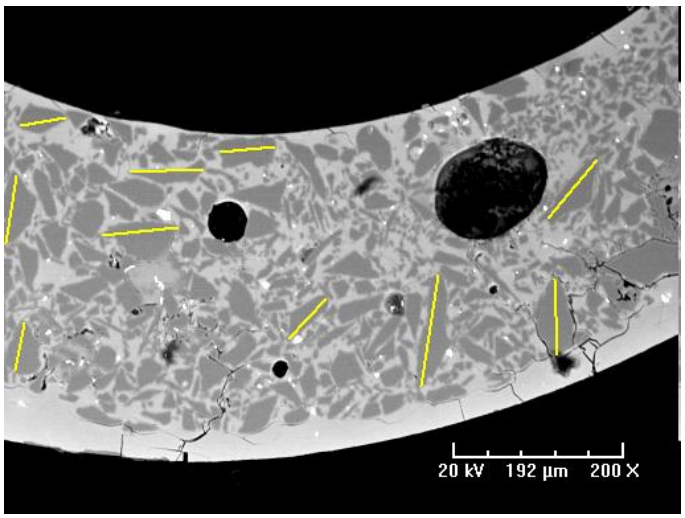


Figure O.30: Profile 2 of bead 2379-5.

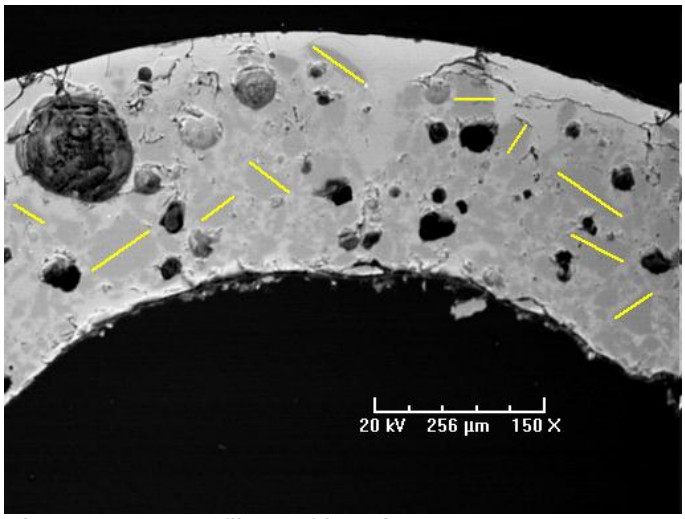


Figure O.31: Profile 1 of bead 2379-6.

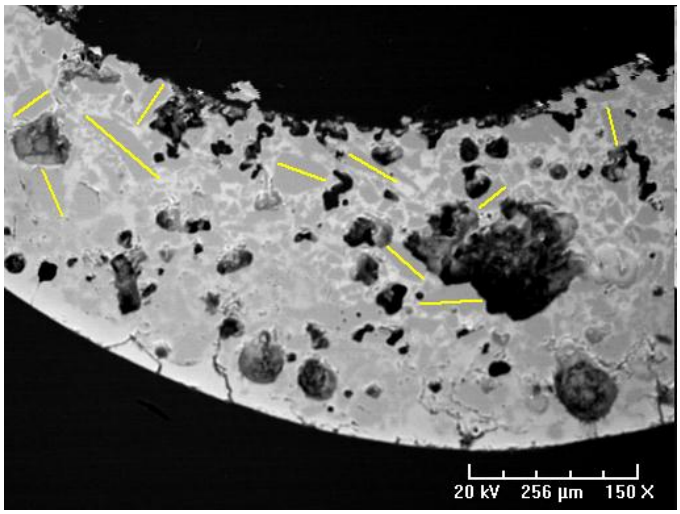


Figure O.32: Profile 2 of bead 2379-6.

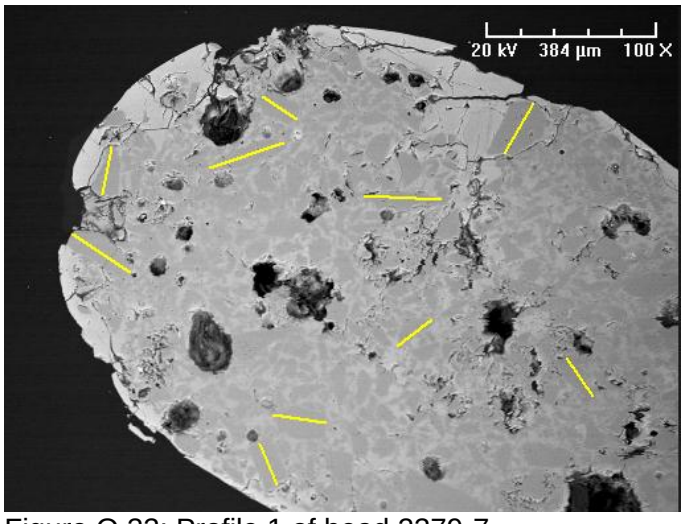


Figure O.33: Profile 1 of bead 2379-7.

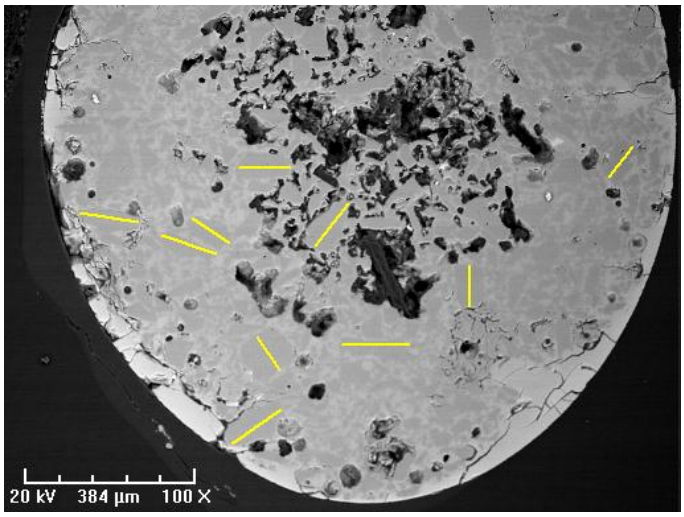


Figure O.34: Profile 2 of bead 2379-7.

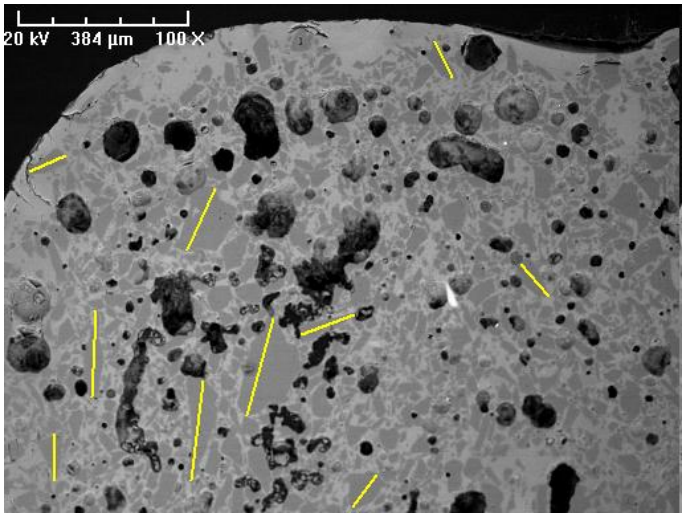


Figure O.35: Profile 1 of bead 2379-8.

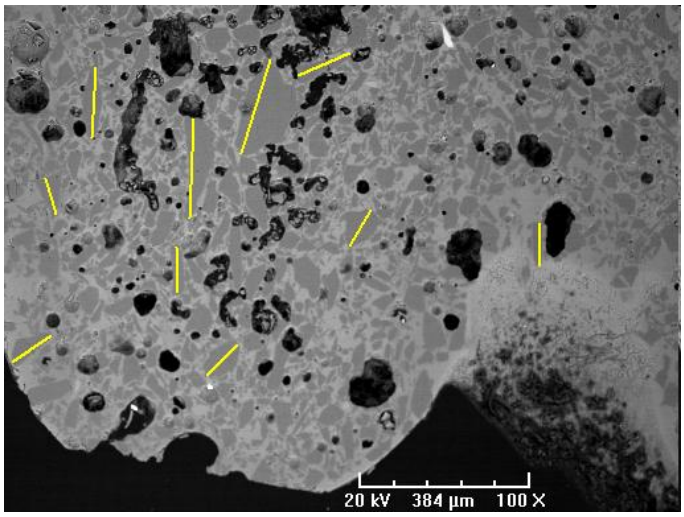


Figure O.36: Profile 2 of bead 2379-8.

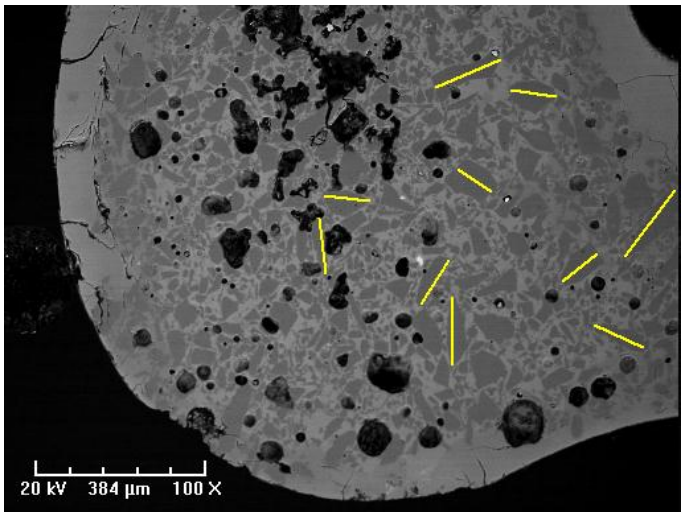


Figure O.37: Profile 1 of bead 2379-9.

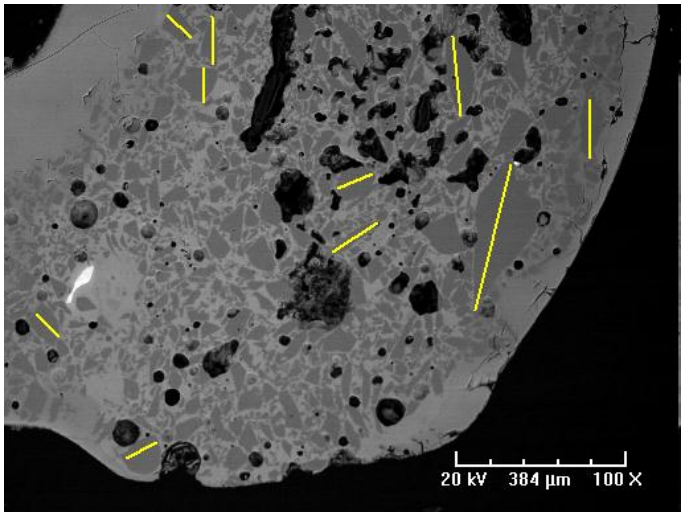


Figure O.38: Profile 2 of bead 2379-9.

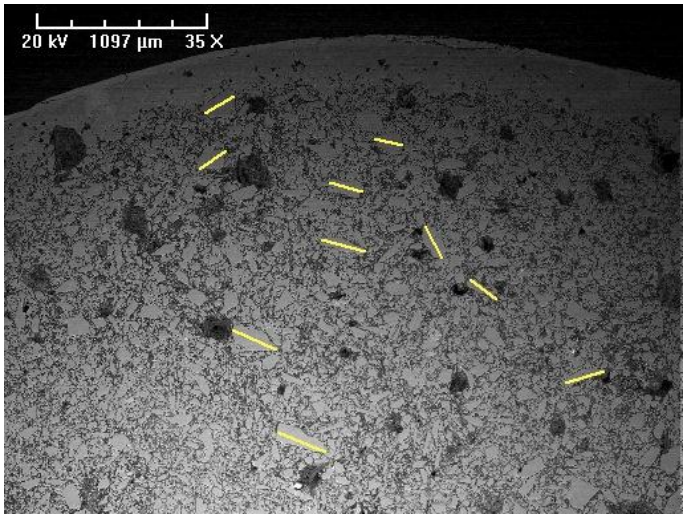


Figure O.39: Profile 1 of bead 2379-10.

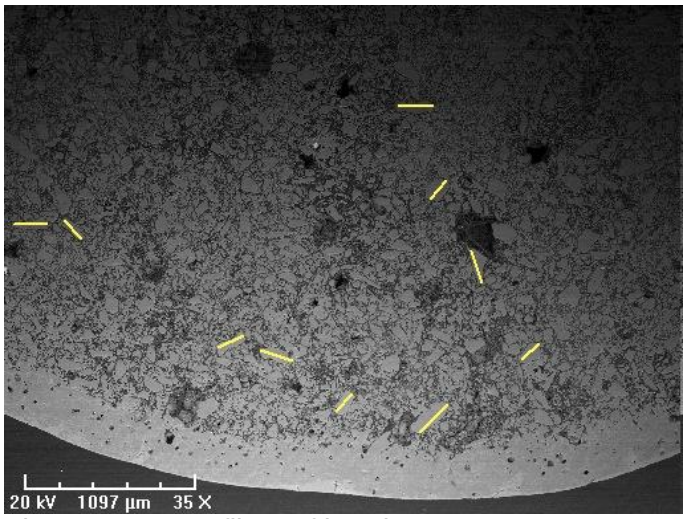


Figure O.40: Profile 2 of bead 2379-10.

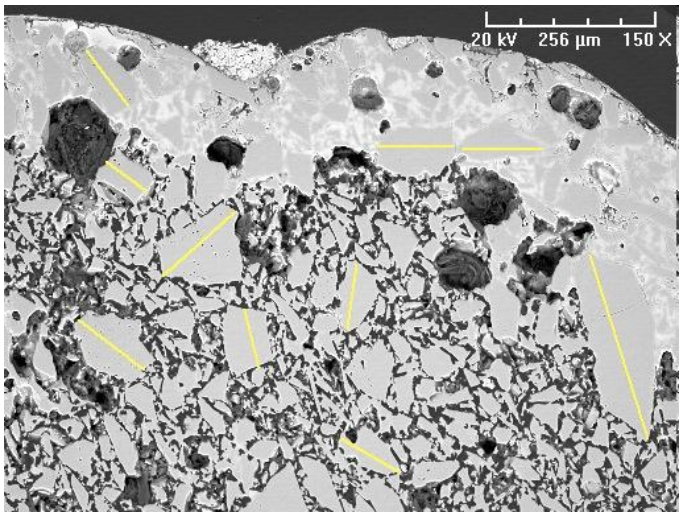


Figure O.41: Profile 1 of bead 2380-1.

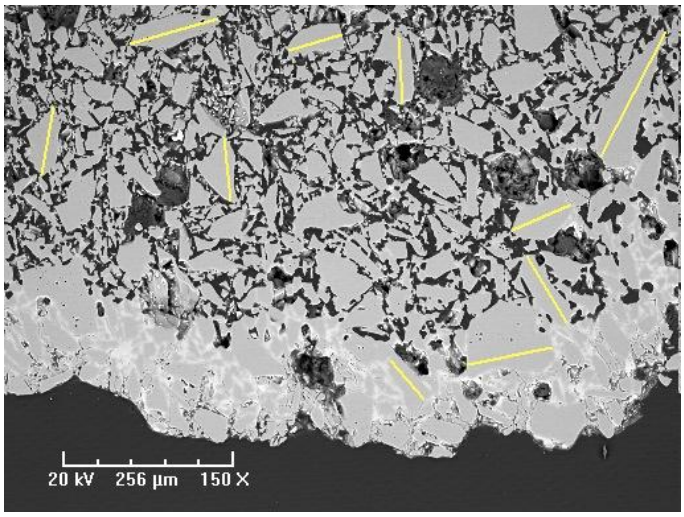


Figure O.42: Profile 2 of bead 2380-1.

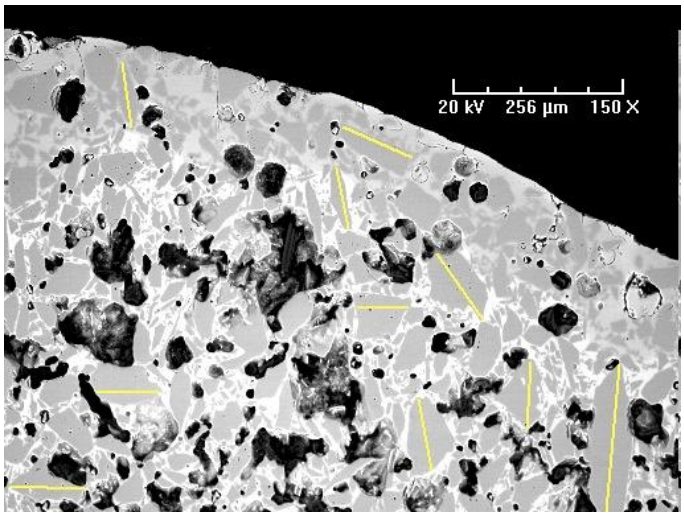


Figure O.43: Profile 1 of bead 2380-2.

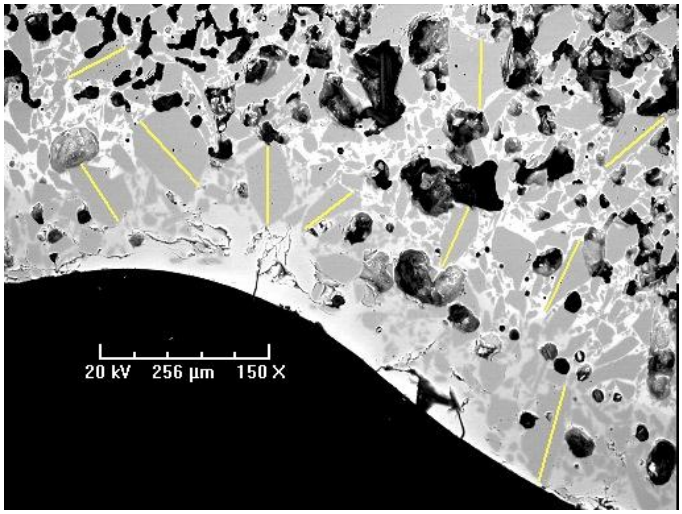


Figure O.44: Profile 2 of bead 2380-2.

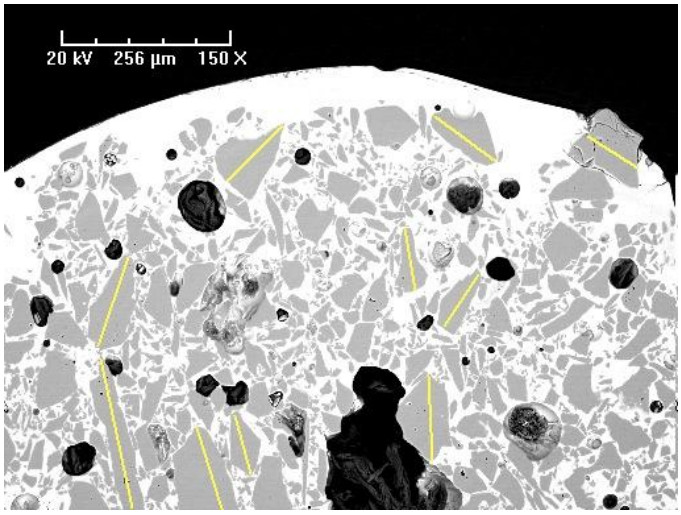


Figure O.45: Profile 1 of bead 2380-3.

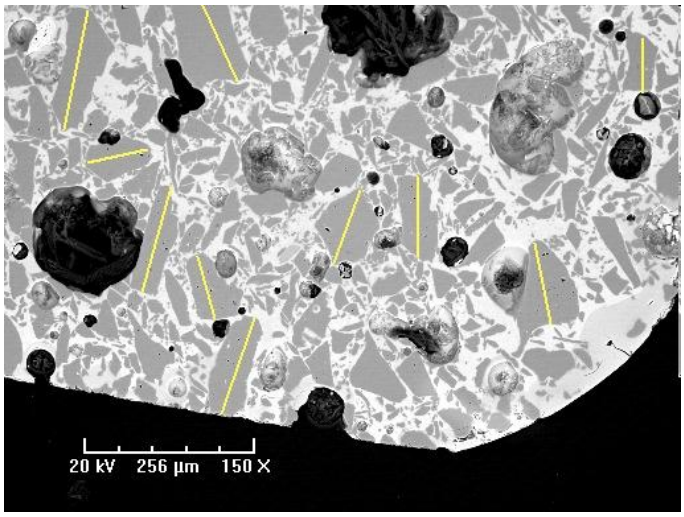


Figure O.46: Profile 2 of bead 2380-3.

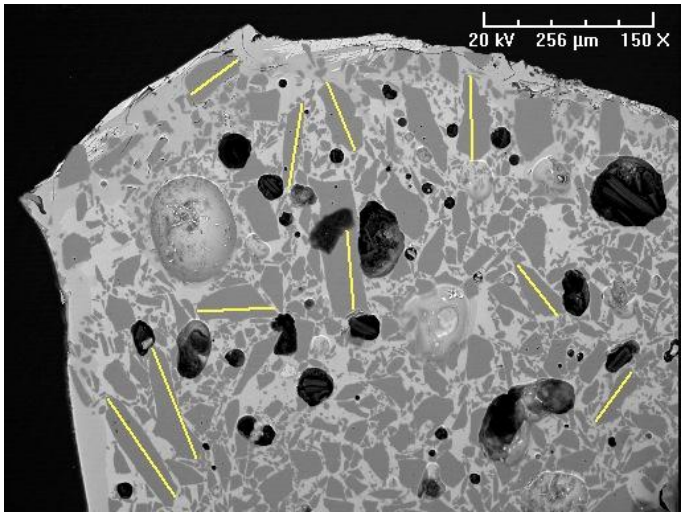


Figure O.47: Profile 1 of bead 2380-4.

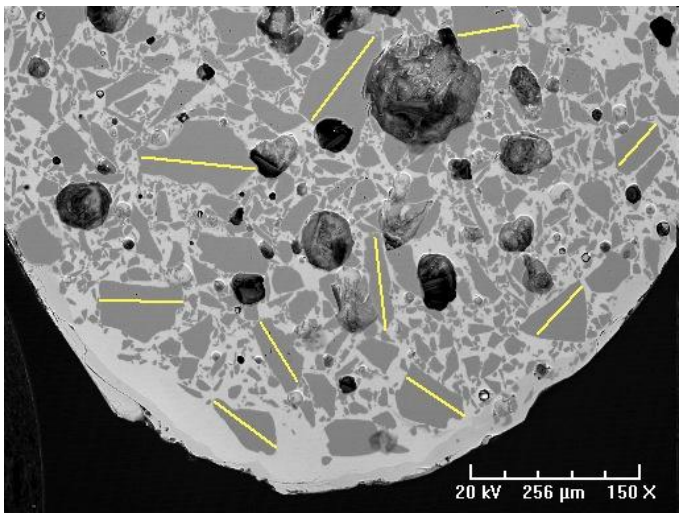


Figure O.48: Profile 2 of bead 2380-4.

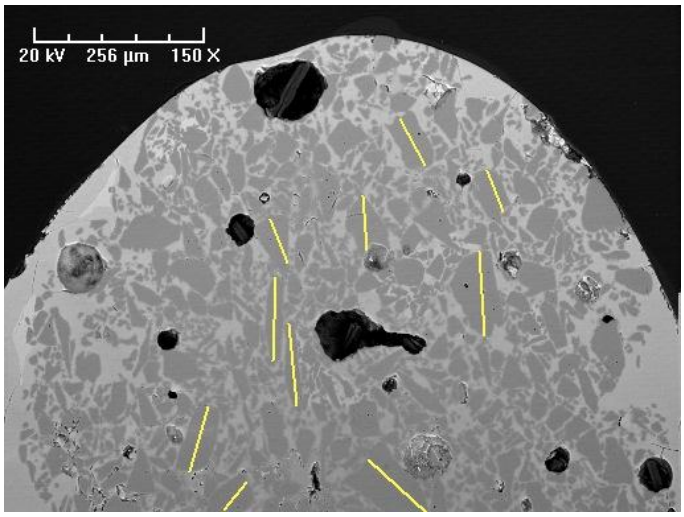


Figure O.49: Profile 1 of bead 2380-5.

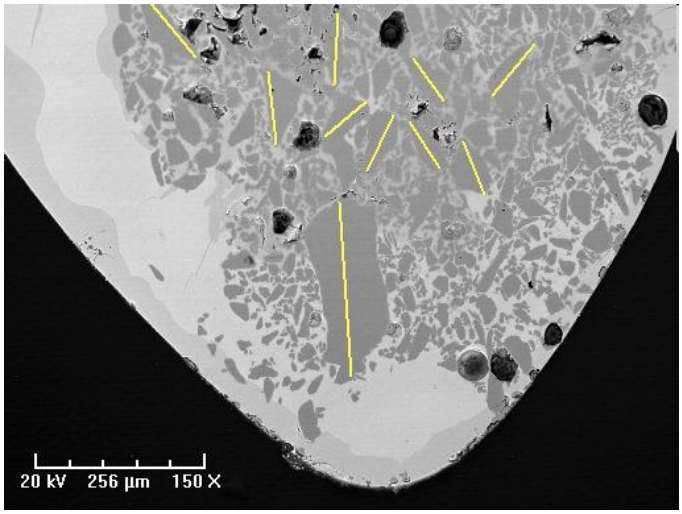


Figure O.50: Profile 2 of bead 2380-5.

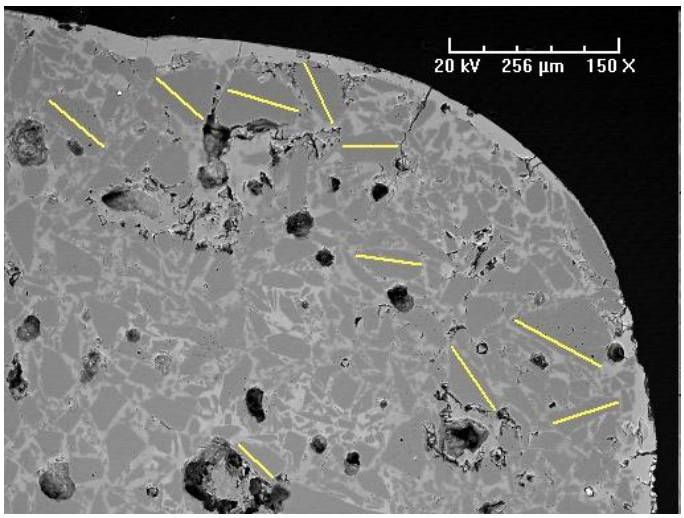


Figure O.51: Profile 1 of bead 2380-6.

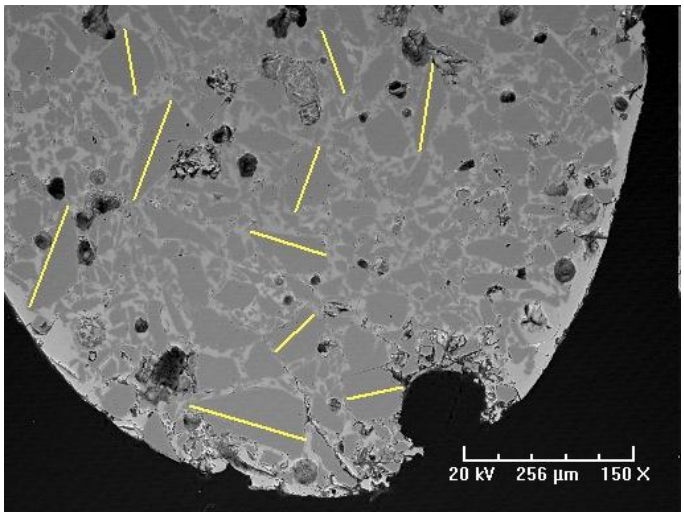


Figure O.52: Profile 2 of bead 2380-6.

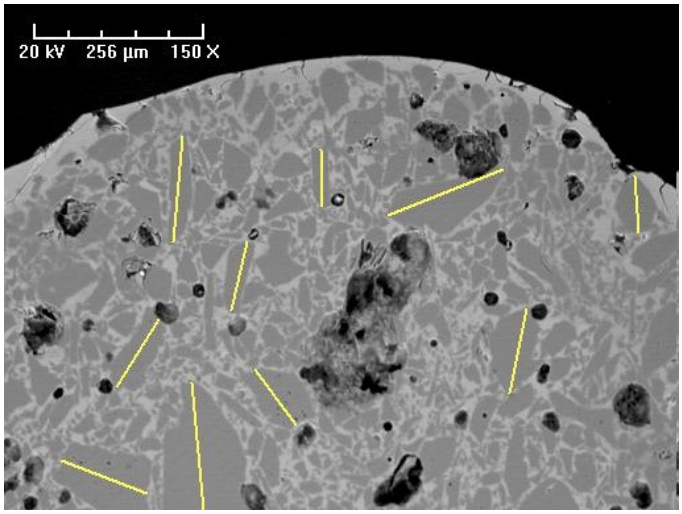


Figure O.53: Profile 1 of bead 2380-7.

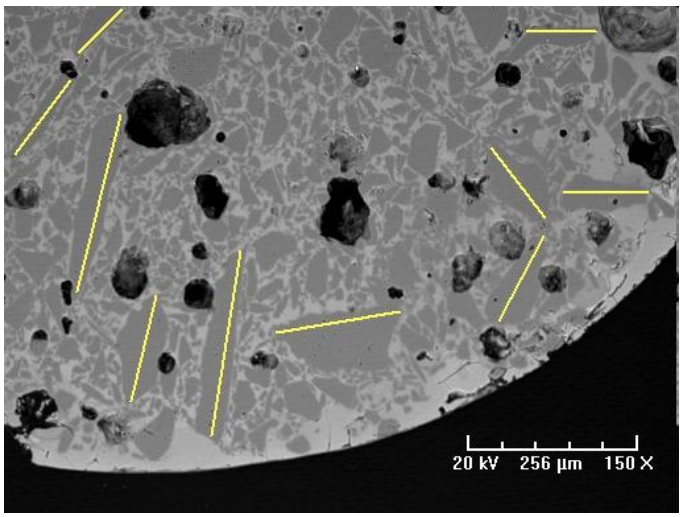


Figure O.54: Profile 2 of bead 2380-7.

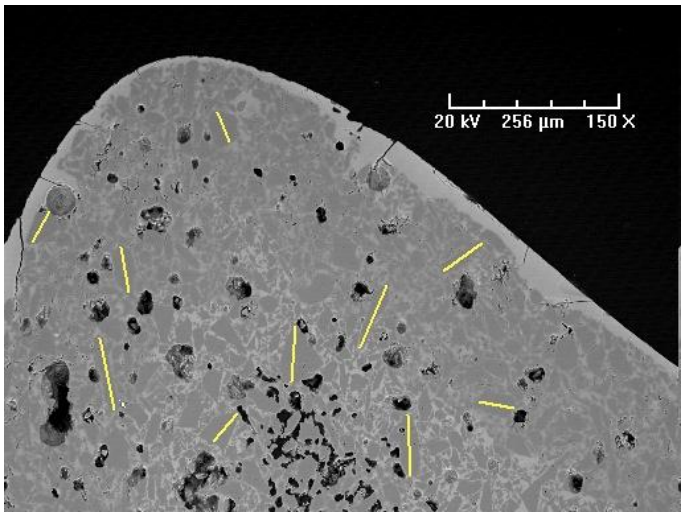


Figure O.55: Profile 1 of bead 2380-8.

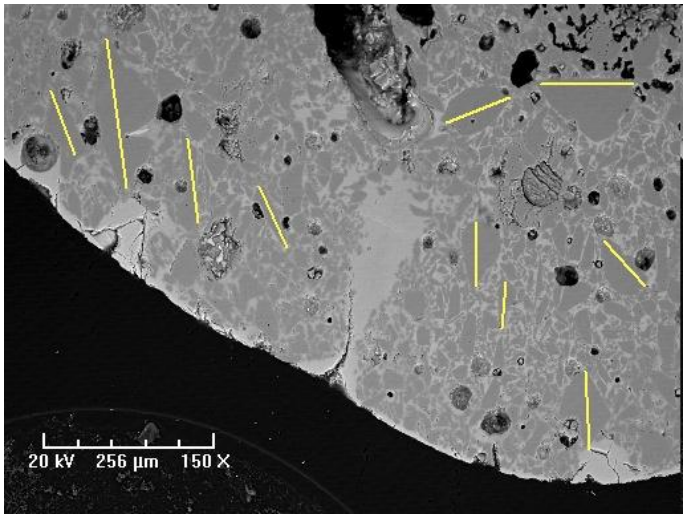


Figure O.56: Profile 2 of bead 2380-8.

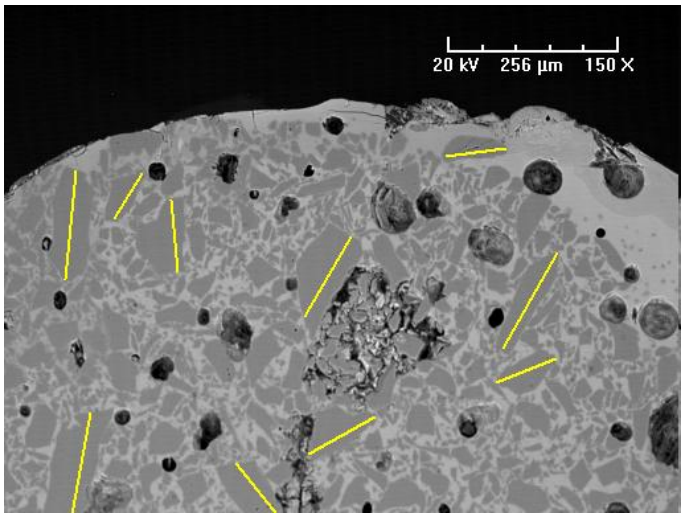


Figure O.57: Profile 1 of bead 2380-9.

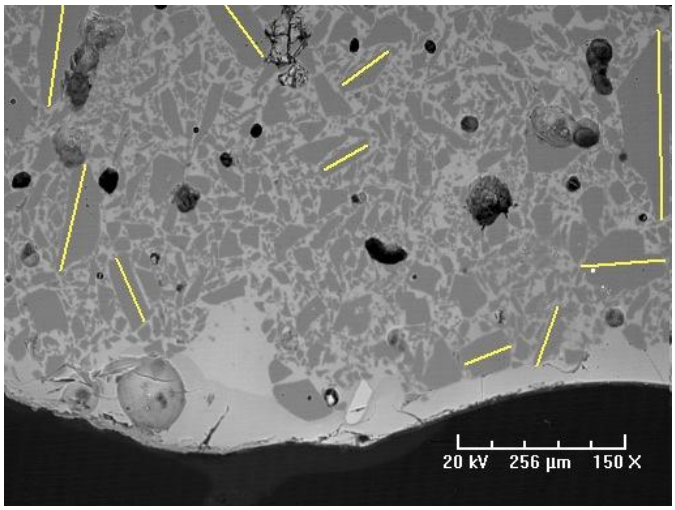


Figure O.58: Profile 2 of bead 2380-9.

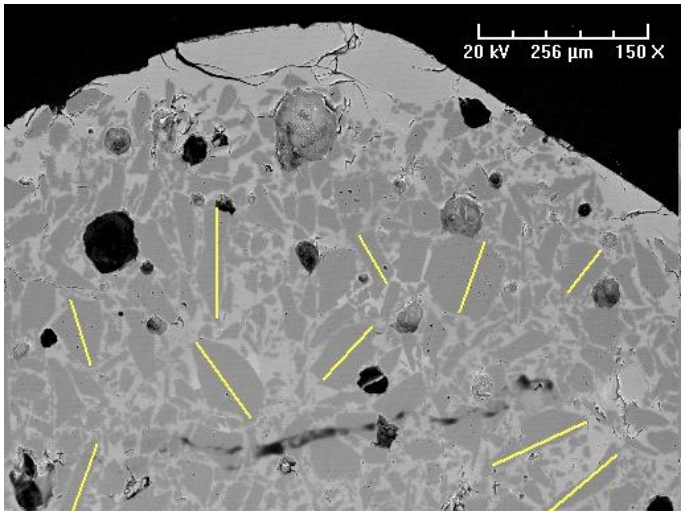


Figure O.59: Profile 1 of bead 2380-10.

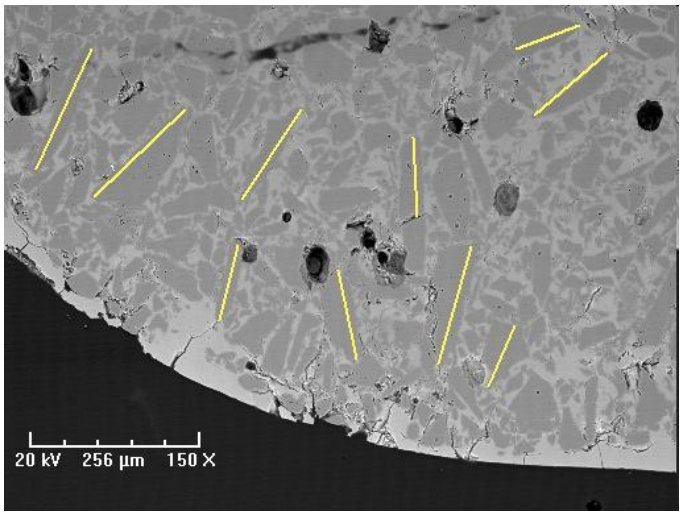


Figure O.60: Profile 2 of bead 2380-10.

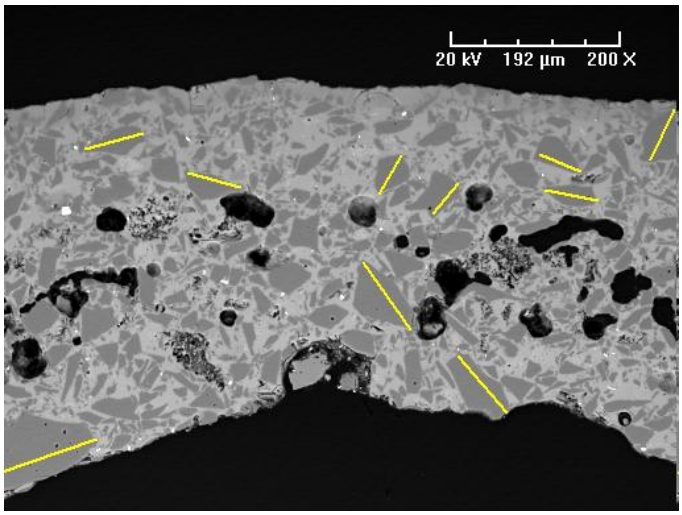


Figure O.61: Profile 1 of bead 4075-1.

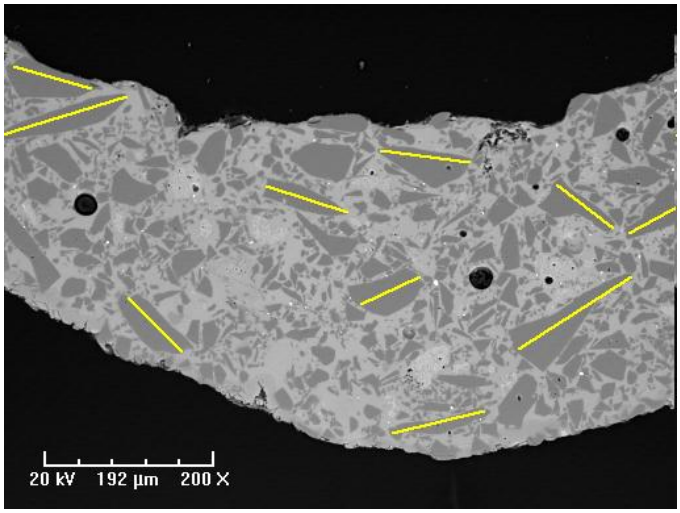


Figure O.62: Profile 2 of bead 4075-1.

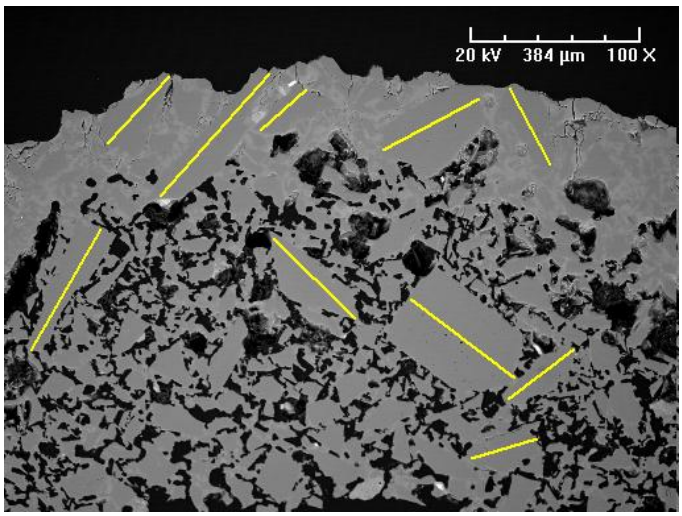


Figure O.63: Profile 1 of bead 4075-2.

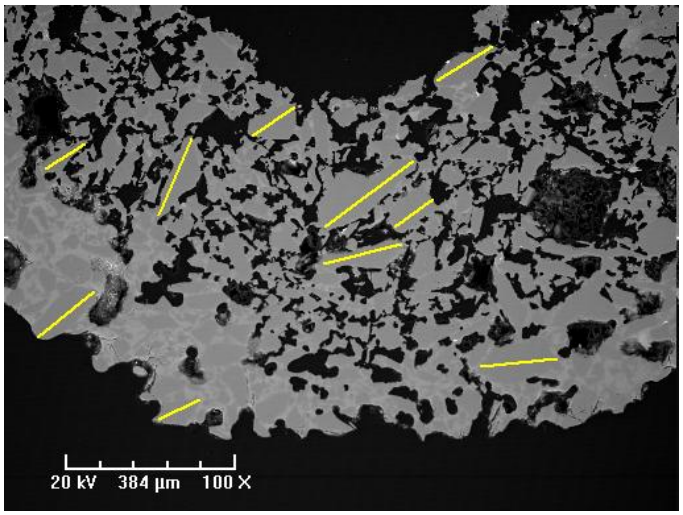


Figure O.64: Profile 2 of bead 4075-2.

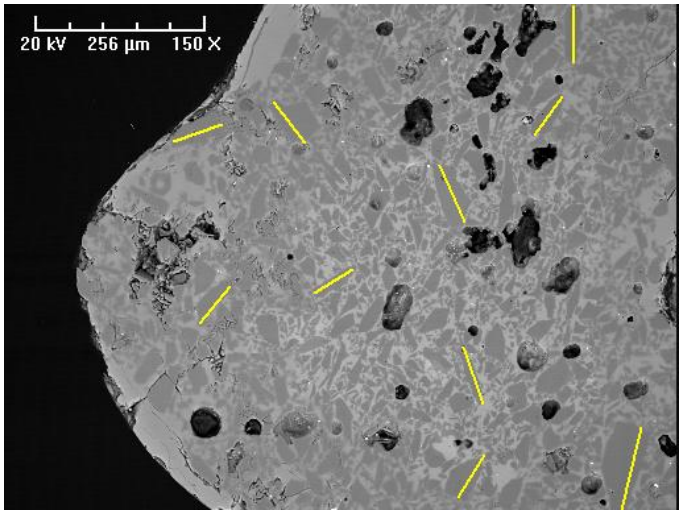


Figure O.65: Profile 1 of bead 4075-3.

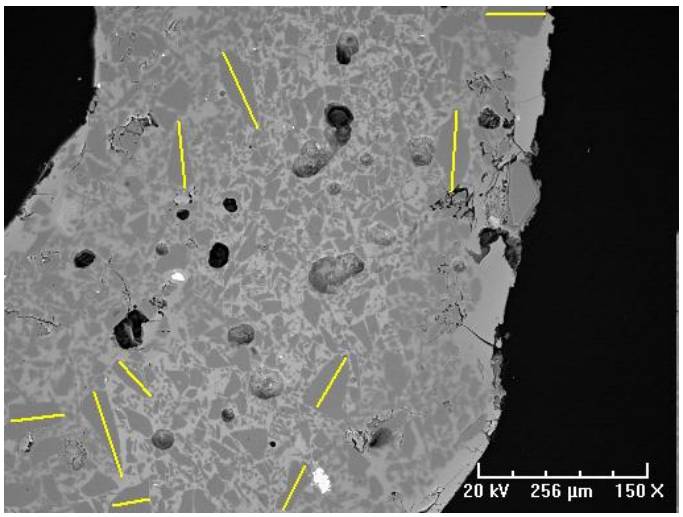


Figure O.66: Profile 2 of bead 4075-3.

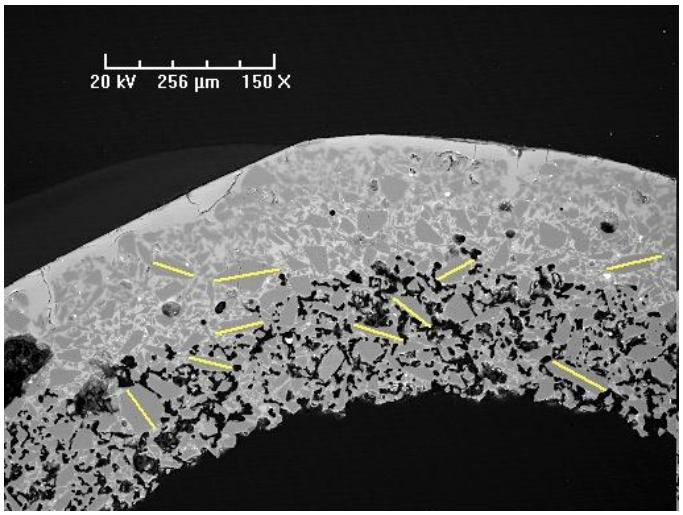


Figure O.67: Profile 1 of bead 4075-4.

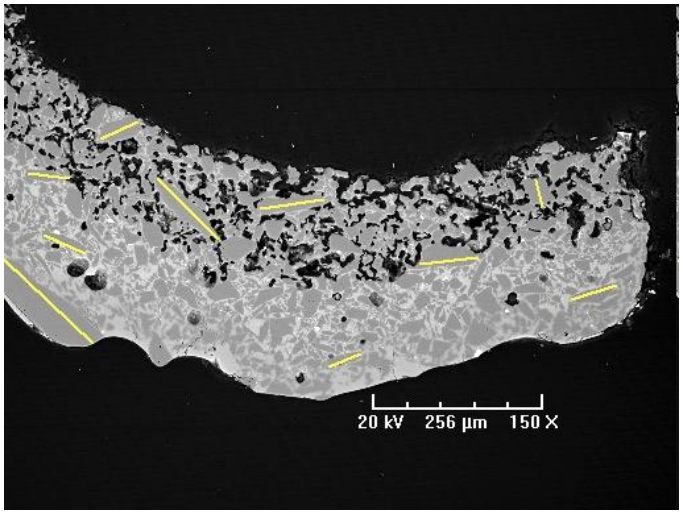


Figure O.68: Profile 2 of bead 4075-4.

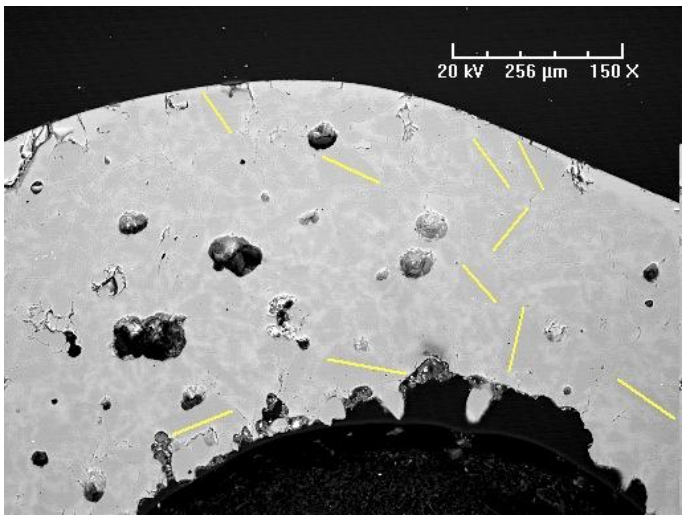


Figure O.69: Profile 1 of bead 4075-5.

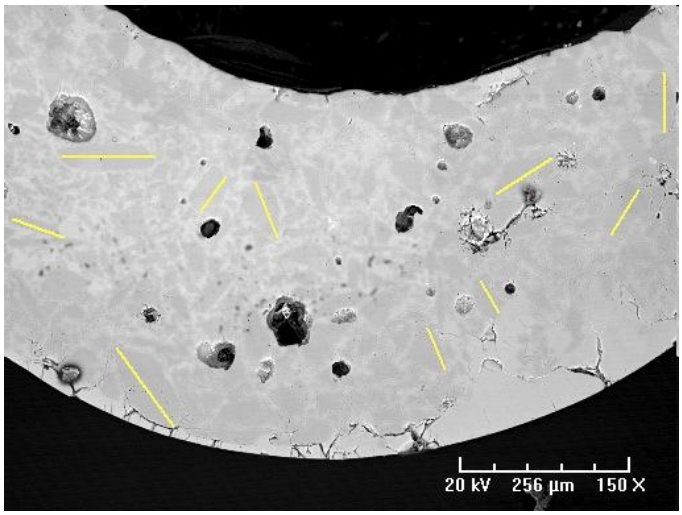


Figure O.70: Profile 2 of bead 4075-5.

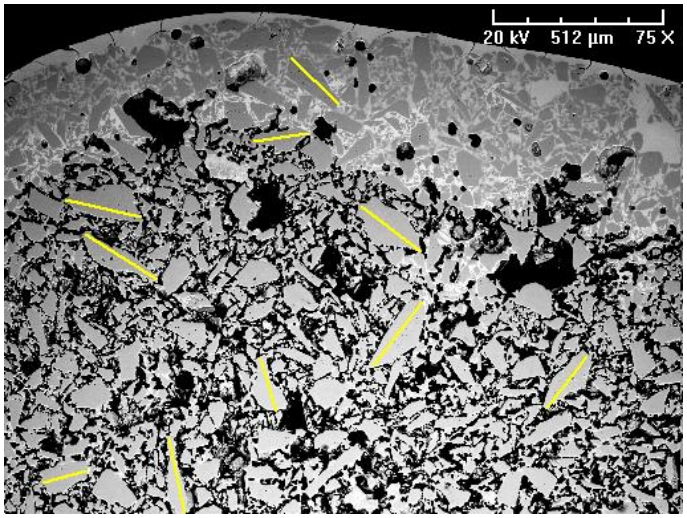


Figure O.71: Profile 1 of bead 2385-1.

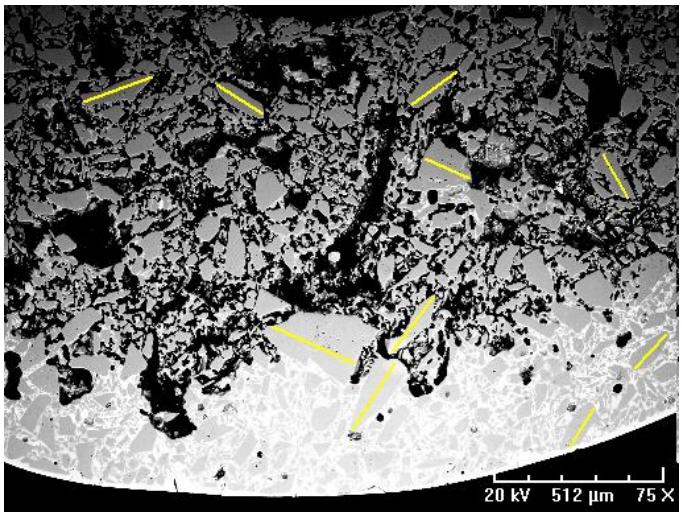


Figure O.72: Profile 2 of bead 2385-1.

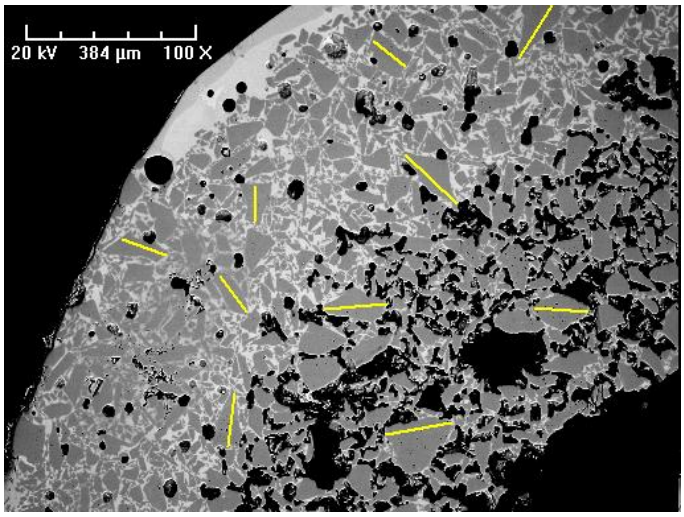


Figure O.73: Profile 1 of bead 2385-2.

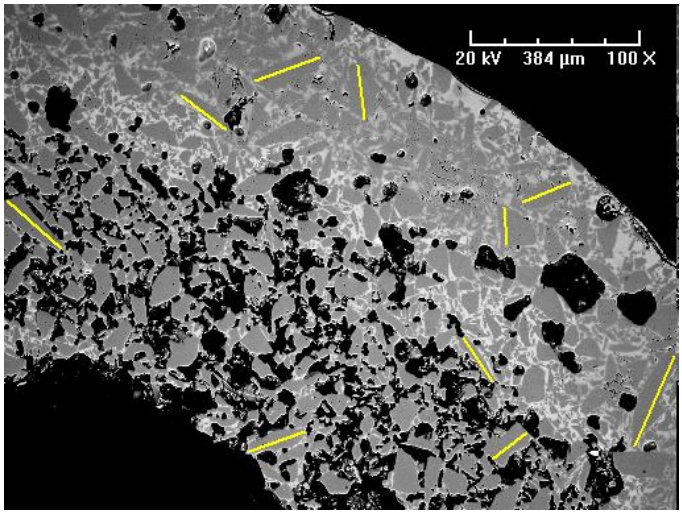


Figure O.74: Profile 2 of bead 2385-2.

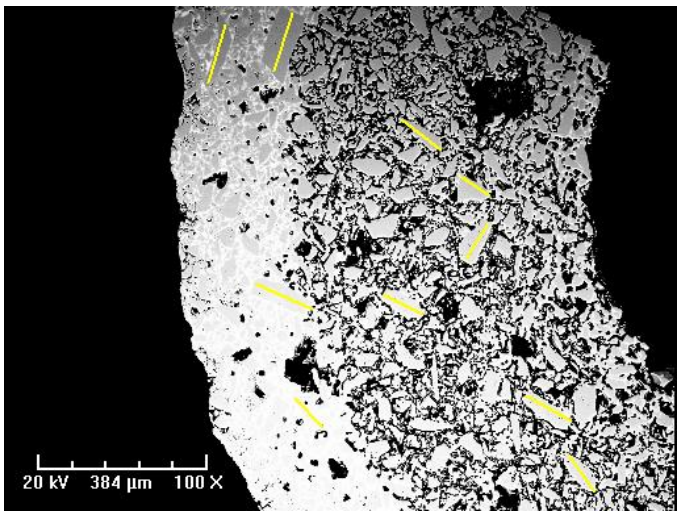


Figure O.75: Profile 1 of bead 2385-3.

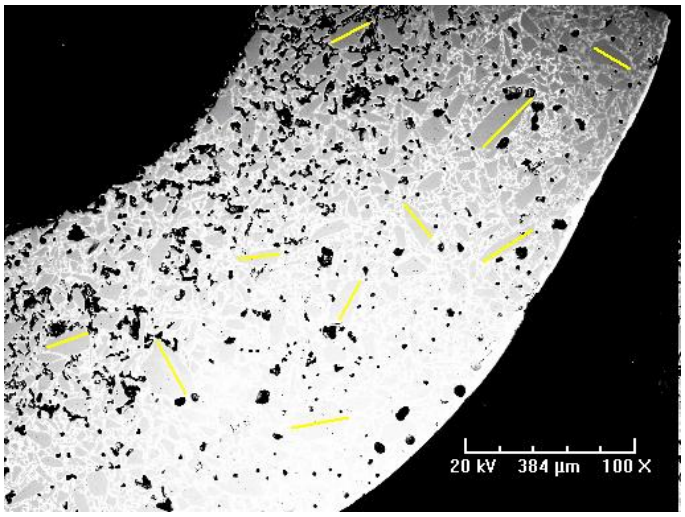


Figure O.76: Profile 2 of bead 2385-3.

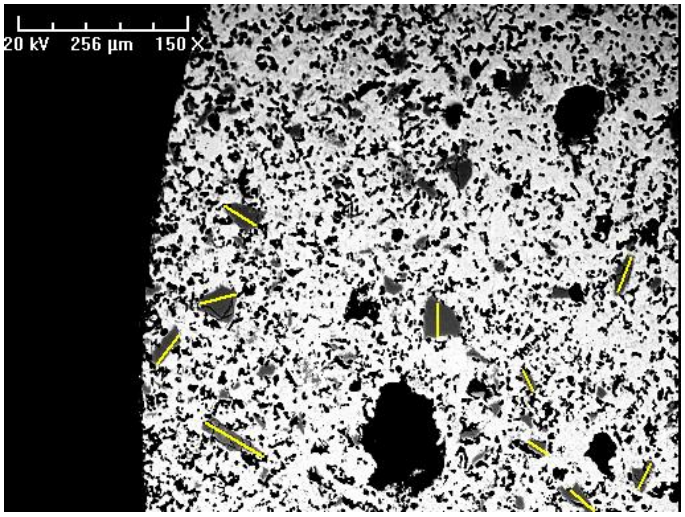


Figure O.77: Profile 1 of bead 2385-4.

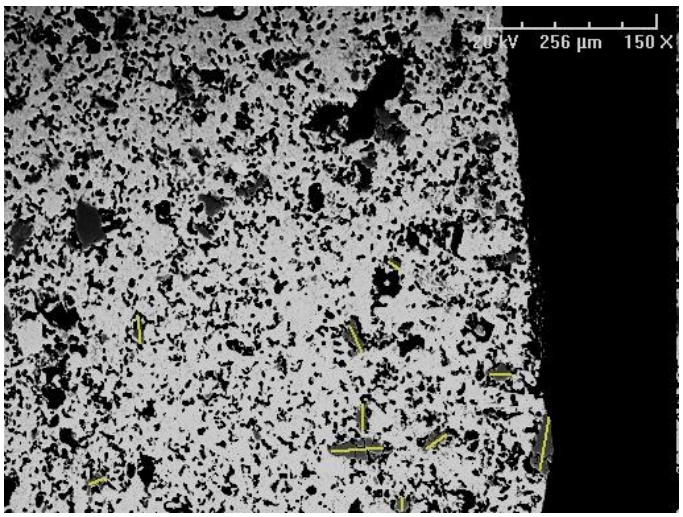


Figure O.78: Profile 2 of bead 2385-4.

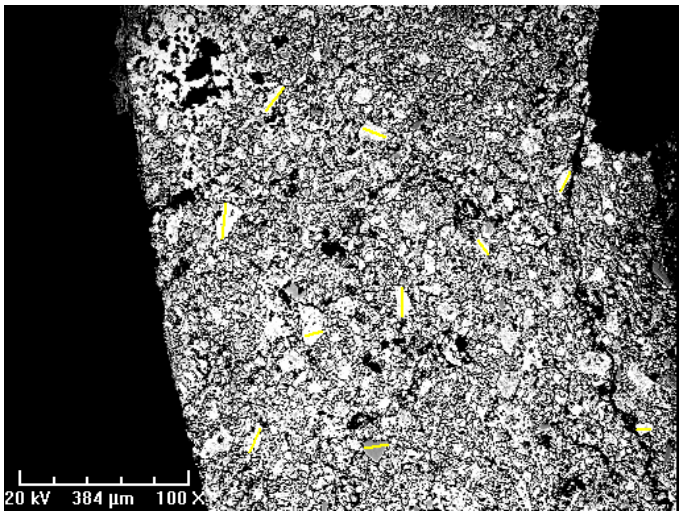


Figure O.79: Profile 1 of bead 2385-5.

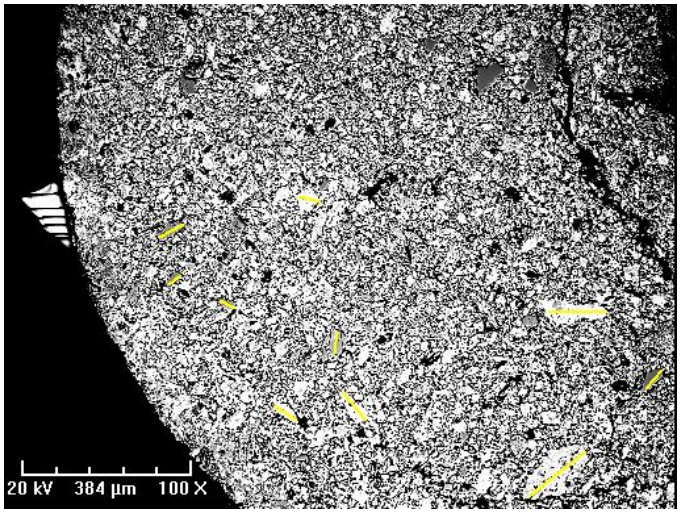


Figure O.80: Profile 2 of bead 2385-5.

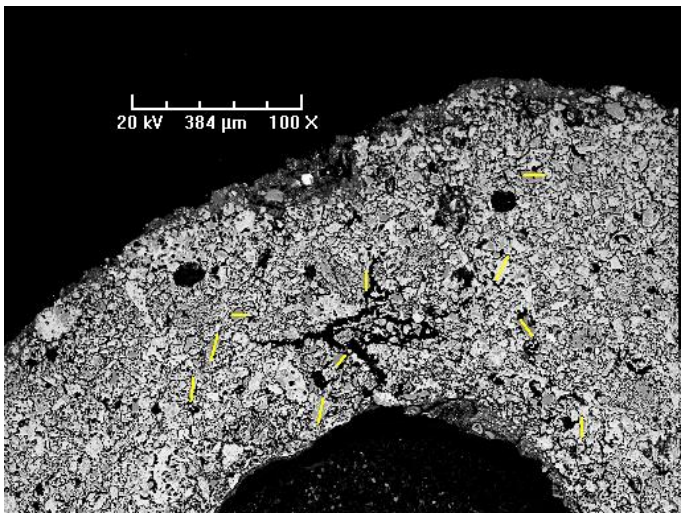


Figure O.81: Profile 1 of bead 2385-6.

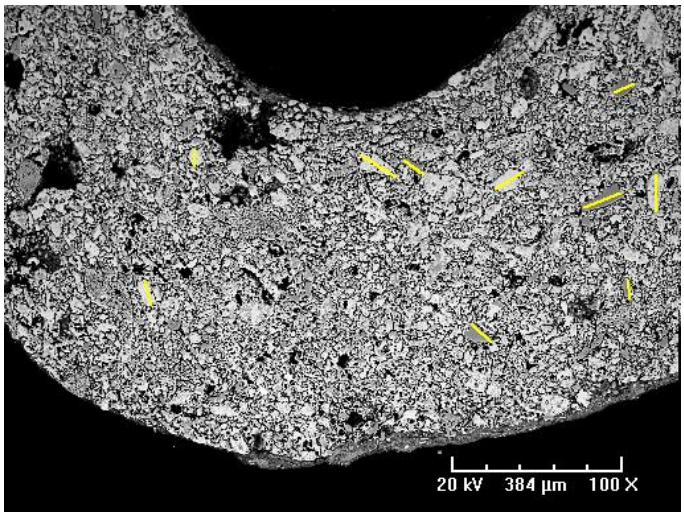


Figure O.82: Profile 2 of bead 2385-6.

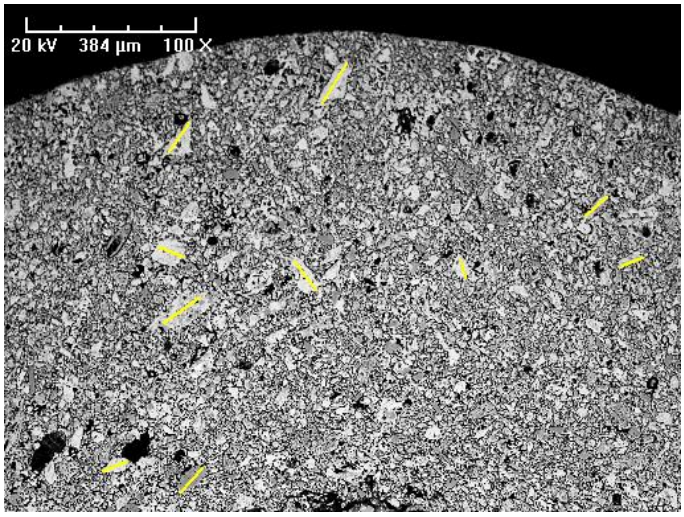


Figure O.83: Profile 1 of bead 2385-7.

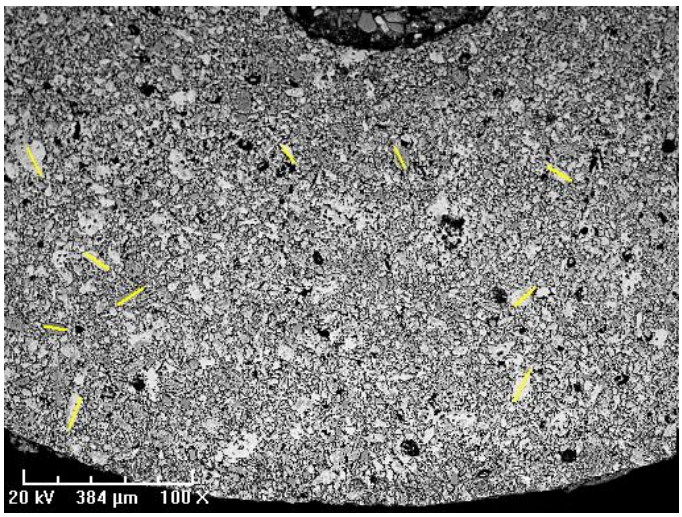


Figure O.84: Profile 2 of bead 2385-7.

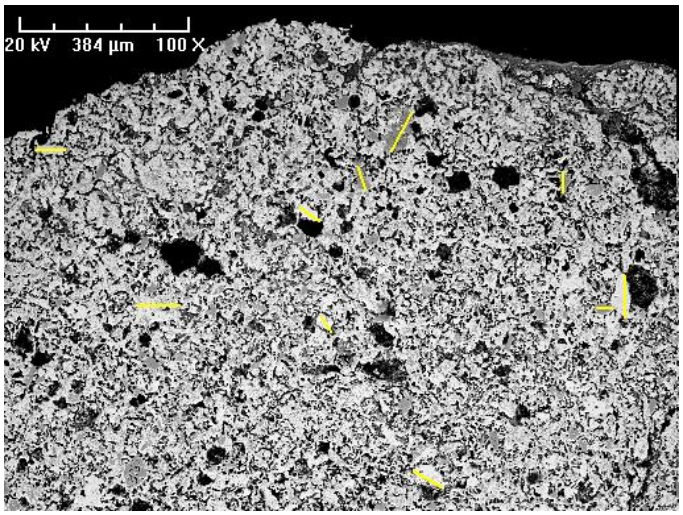


Figure O.85: Profile 1 of bead 2385-8.

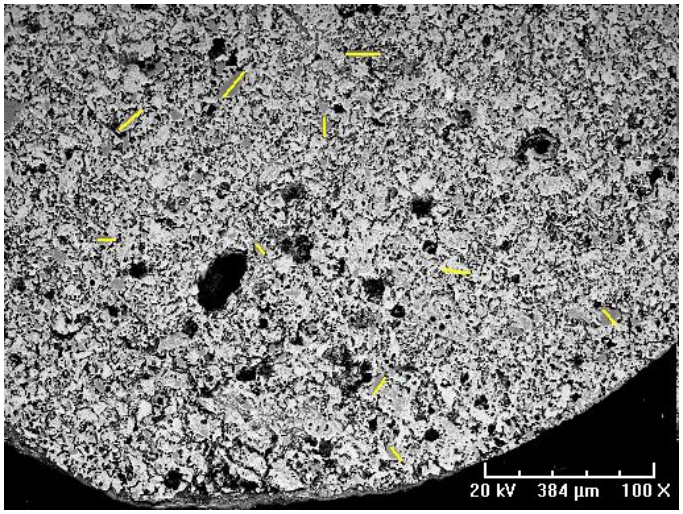


Figure O.86: Profile 2 of bead 2385-8.

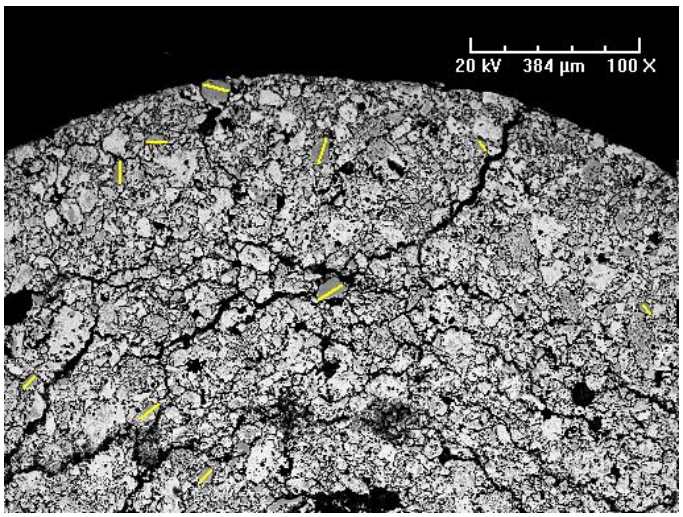


Figure O.87: Profile 1 of bead 2385-9.

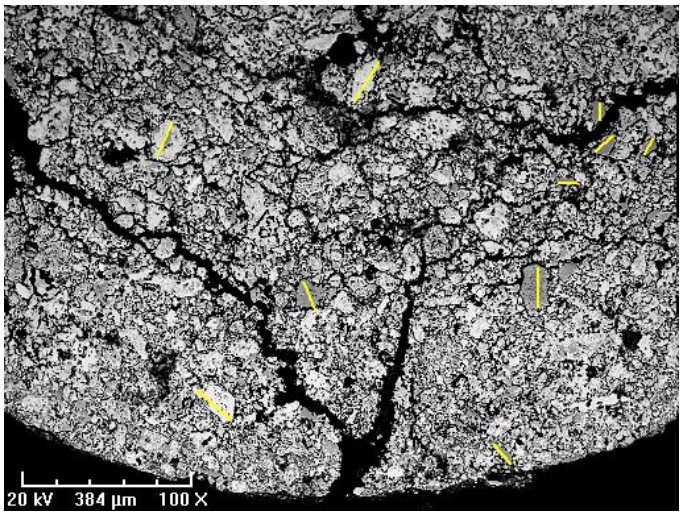


Figure O.88: Profile 2 of bead 2385-9.

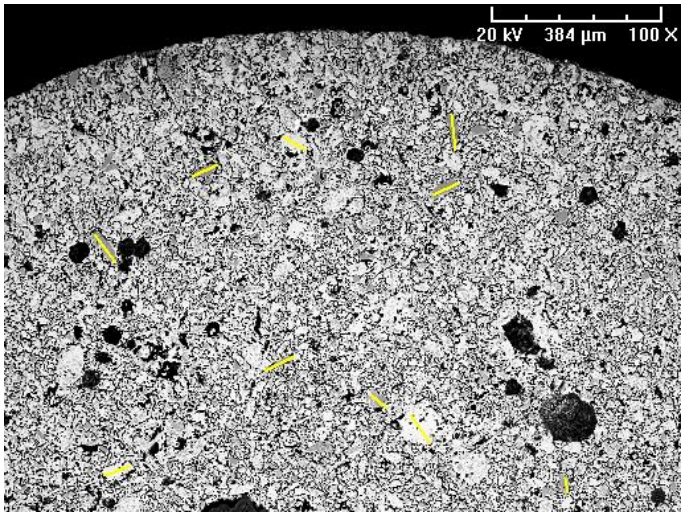


Figure O.89: Profile 1 of bead 2385-10.

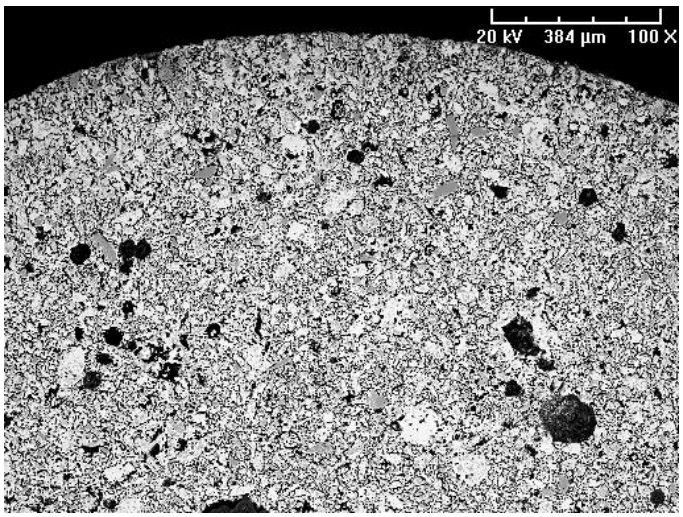


Figure O.90: Profile 2 of bead 2385-10.

Experimental Beads

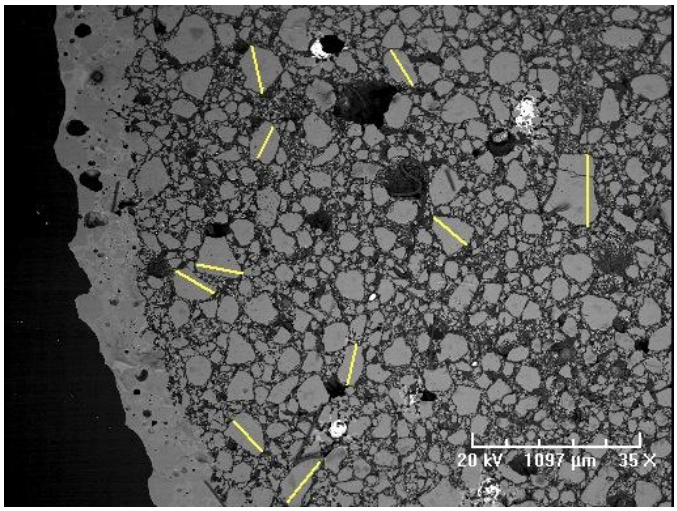


Figure O.91: Profile 1 of Batch 15.

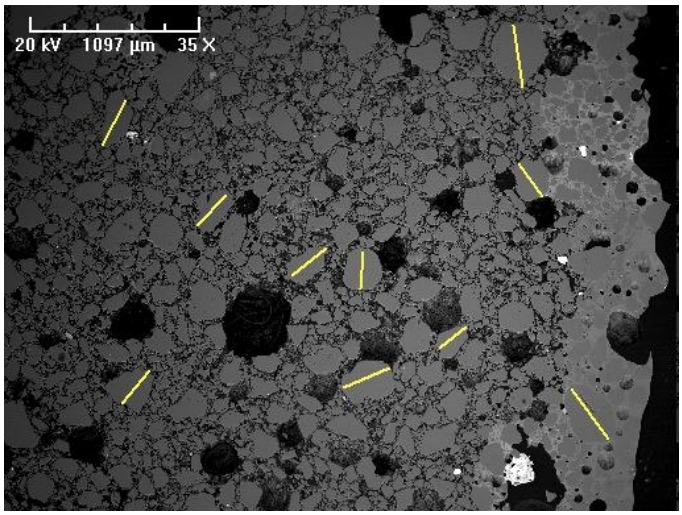


Figure O.92: Profile 2 of Batch 15.

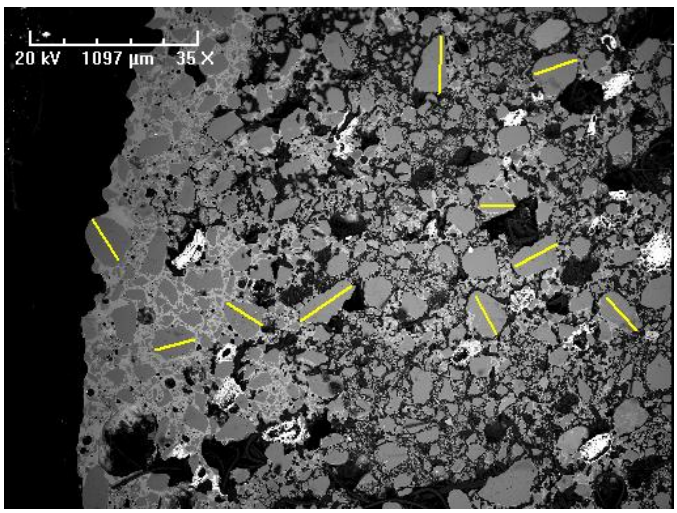


Figure O.93: Profile 1 of Batch 17.

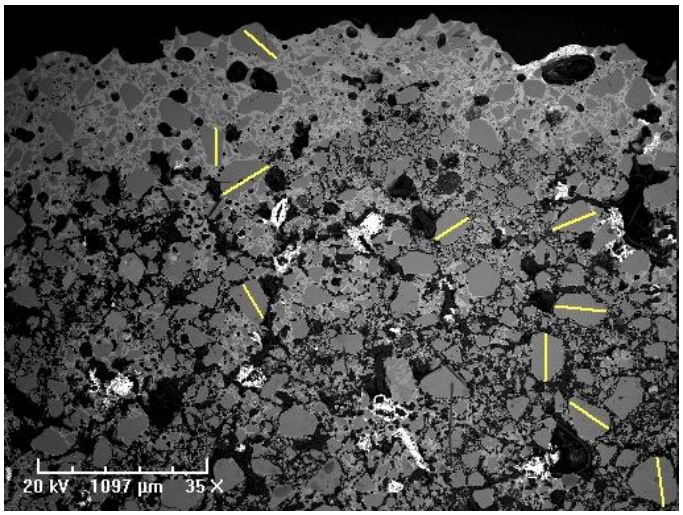


Figure O.94: Profile 2 of Batch 17.

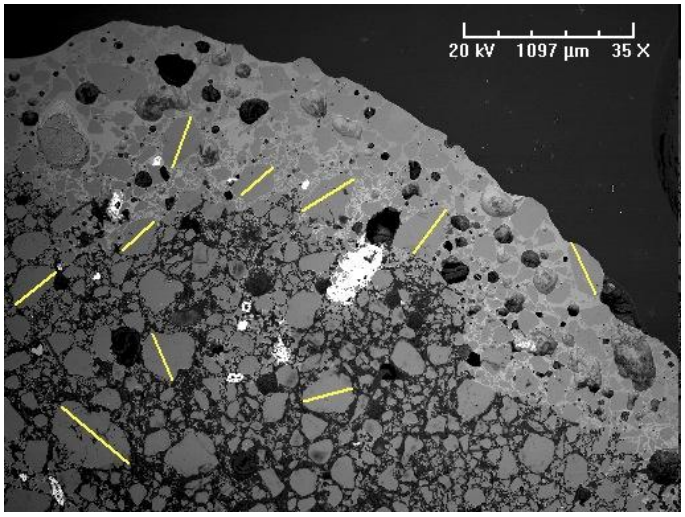


Figure O.95: Profile 1 of Batch 19.

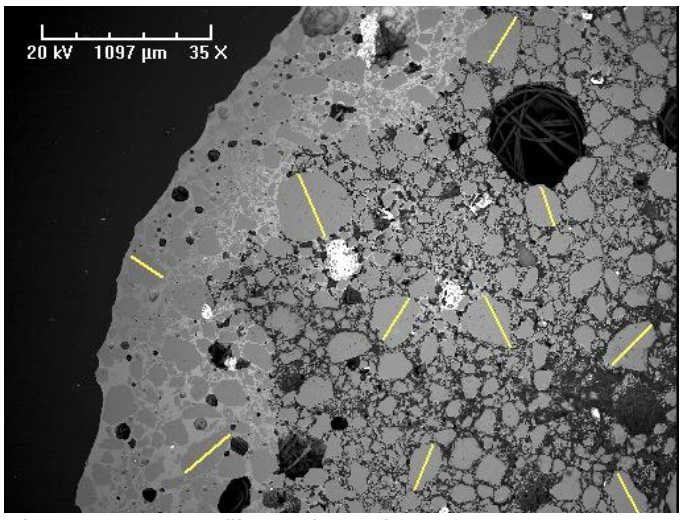


Figure O.96: Profile 2 of Batch 19.

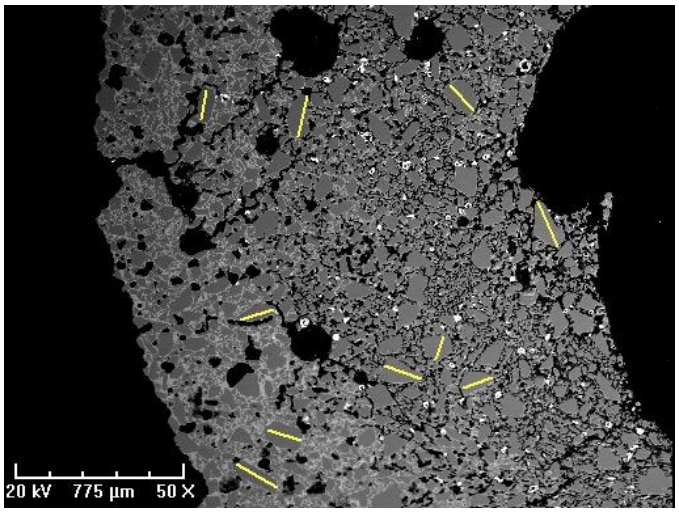


Figure O.97: Profile 1 of Batch 26.

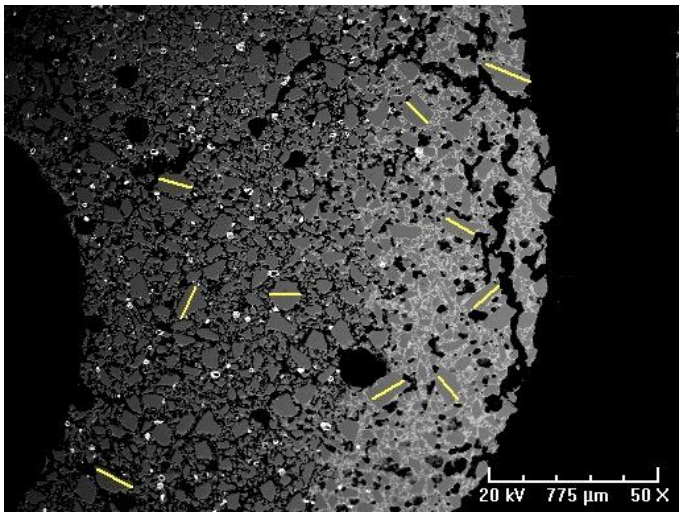


Figure O.98: Profile 2 of Batch 26.

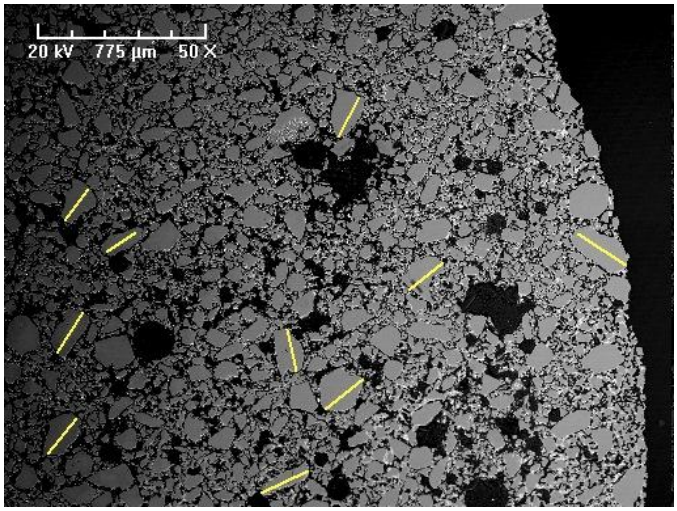


Figure O.99: Profile 1 of Batch 35.

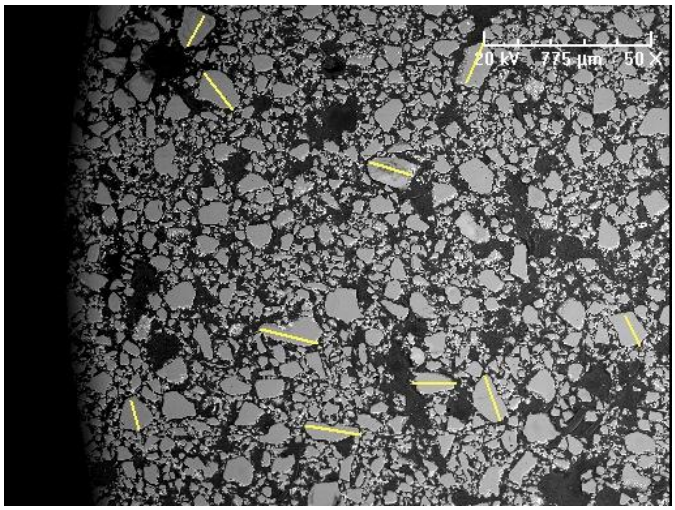


Figure O.100: Profile 2 of Batch 35.

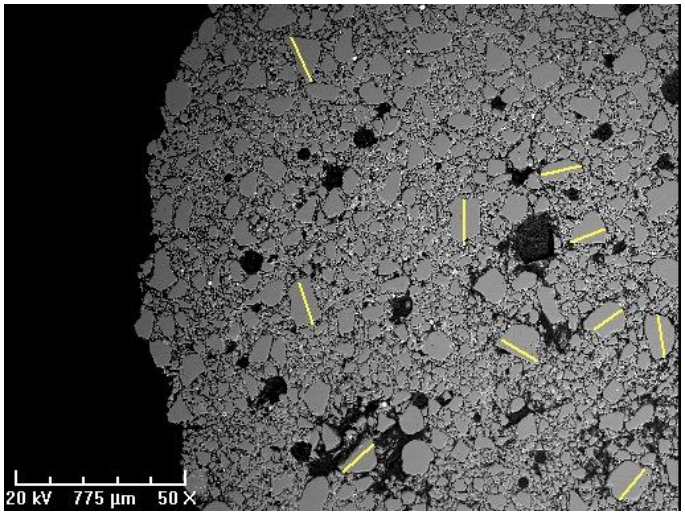


Figure O.101: Profile 1 of Batch 36.

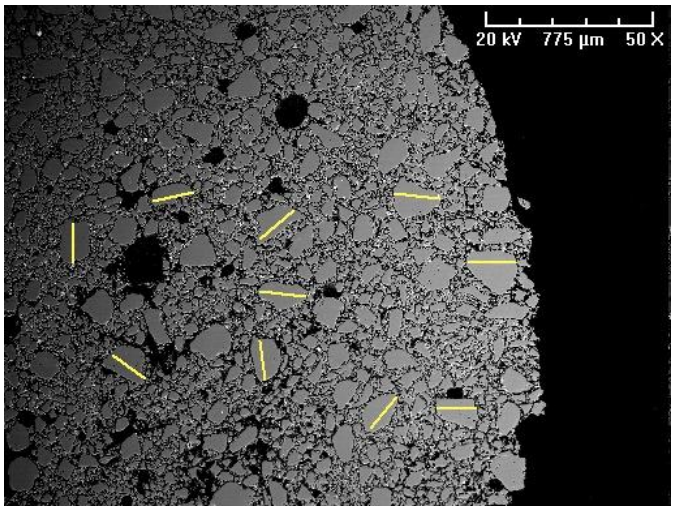


Figure O.102: Profile 2 of Batch 36.

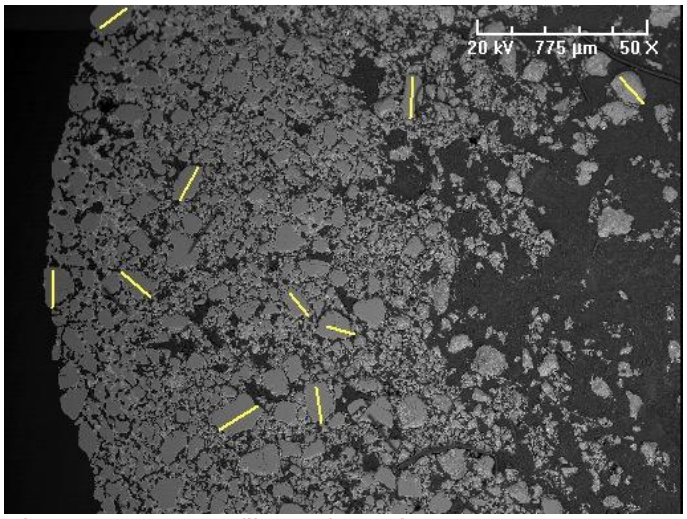


Figure O.103: Profile 1 of Batch 38.

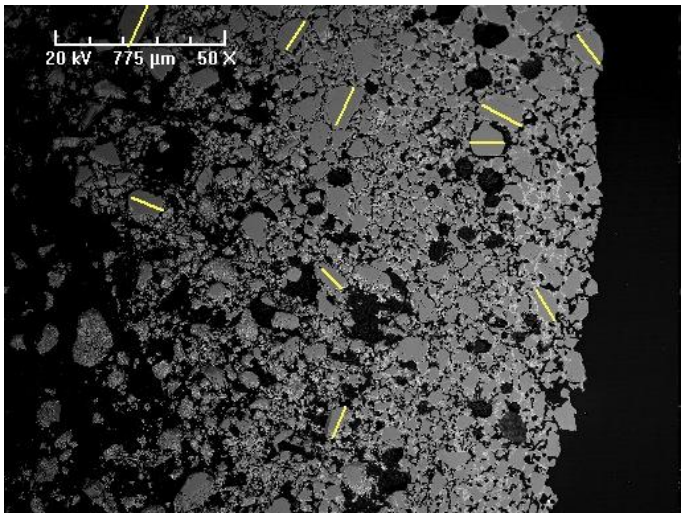


Figure O.104: Profile 2 of Batch 38.

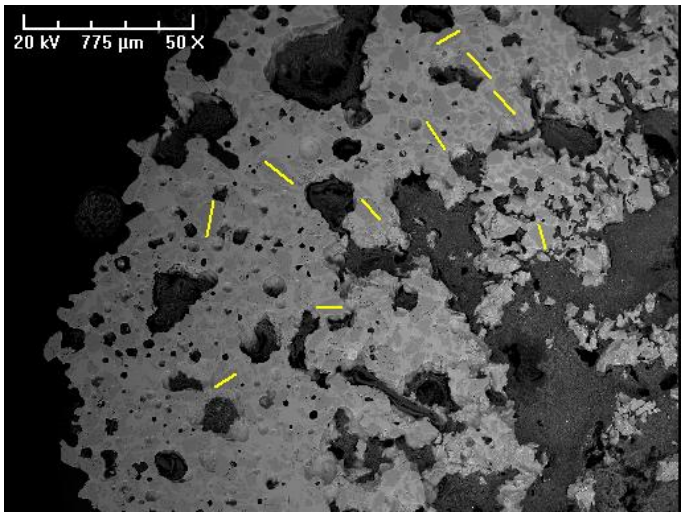


Figure O.105: Profile 1 of Batch 39.

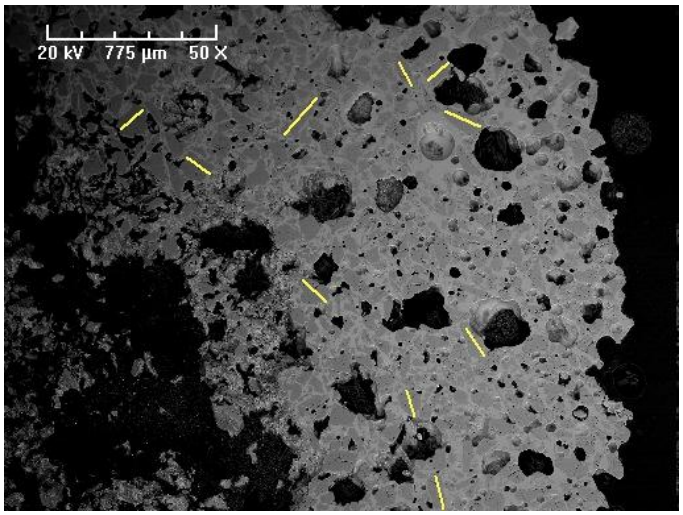


Figure O.106: Profile 2 of Batch 39.

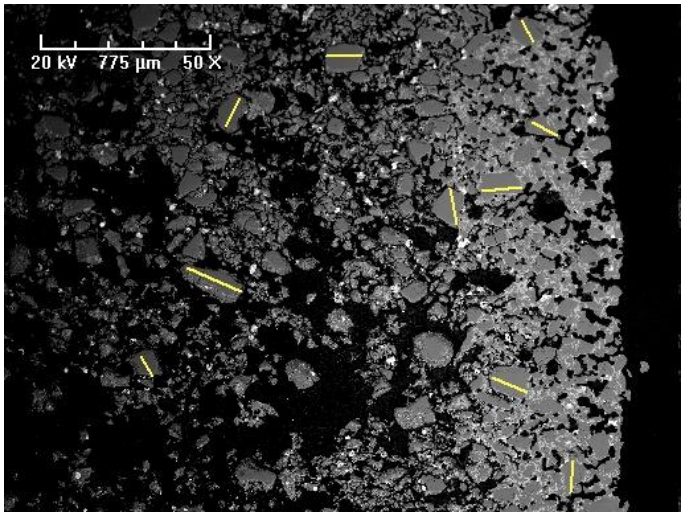


Figure O.107: Profile 1 of Batch 40.

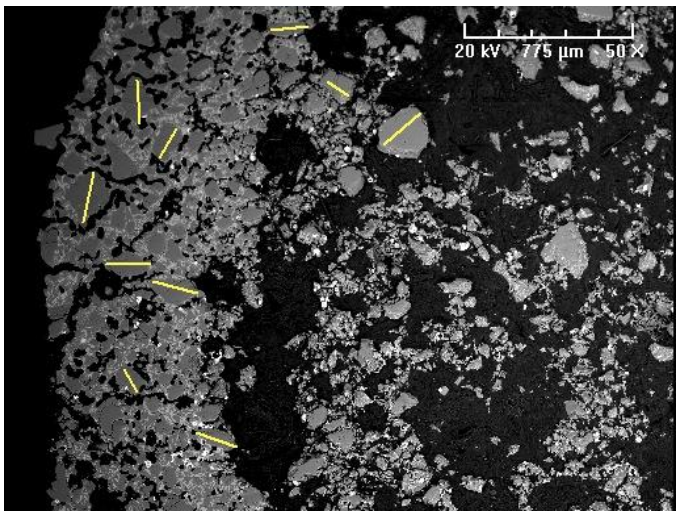


Figure O.108: Profile 2 of Batch 40.

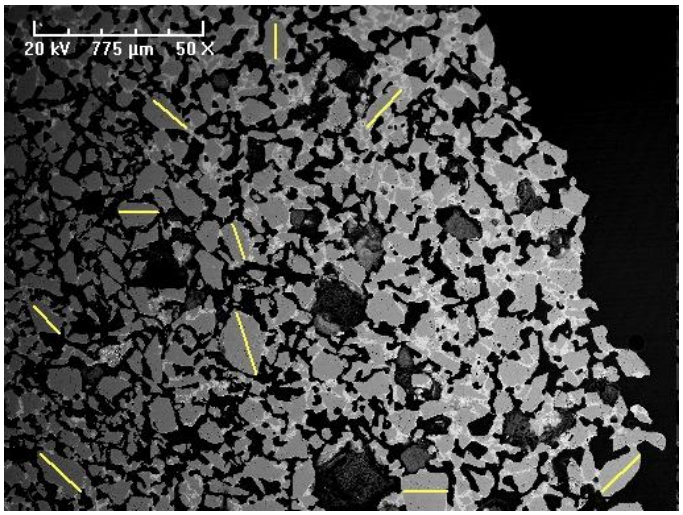


Figure O.109: Profile 1 of Batch 41.

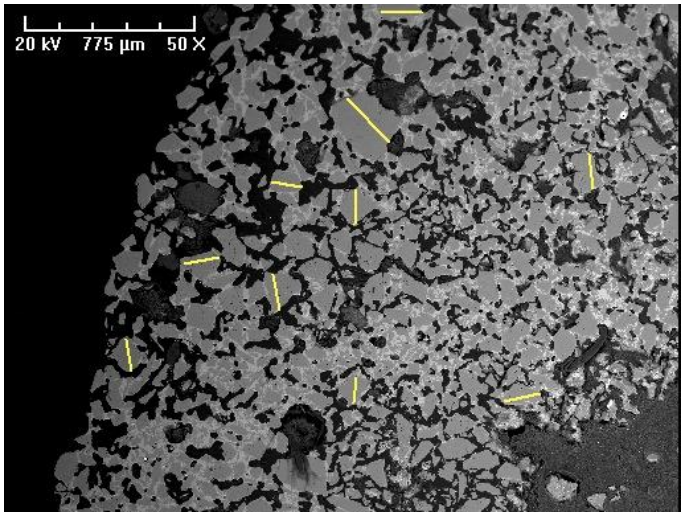


Figure O.110: Profile 2 of Batch 41.

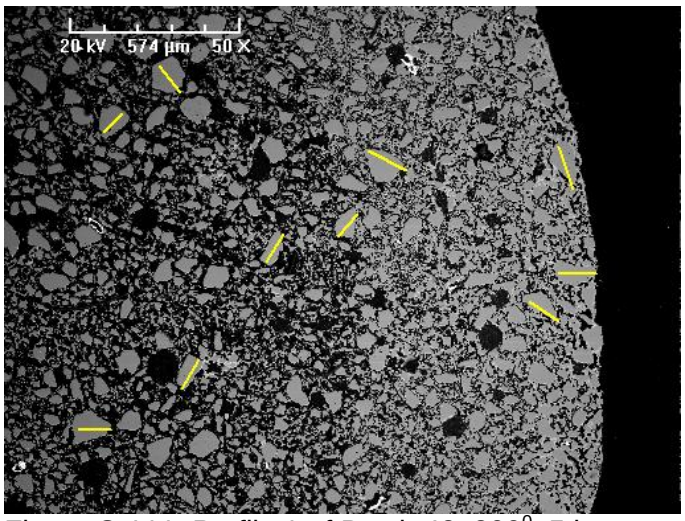


Figure O.111: Profile 1 of Batch 42, 800^{0}, 5 hr.

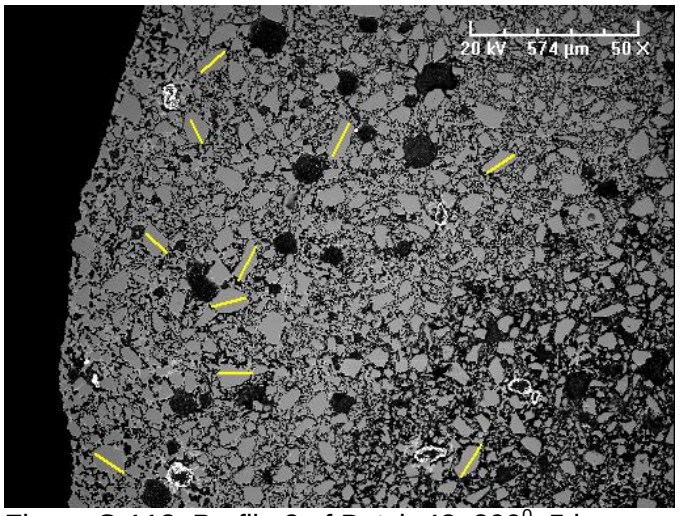


Figure O.112: Profile 2 of Batch 42, 800^0, 5 hr.

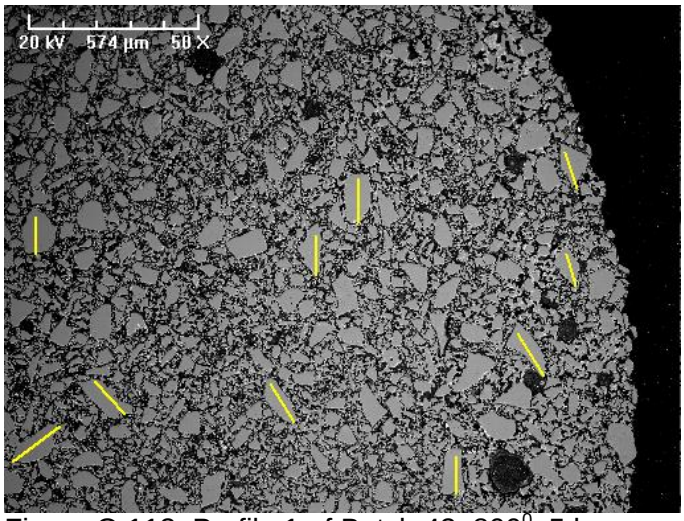


Figure O.113: Profile 1 of Batch 43, 800^0, 5 hr.

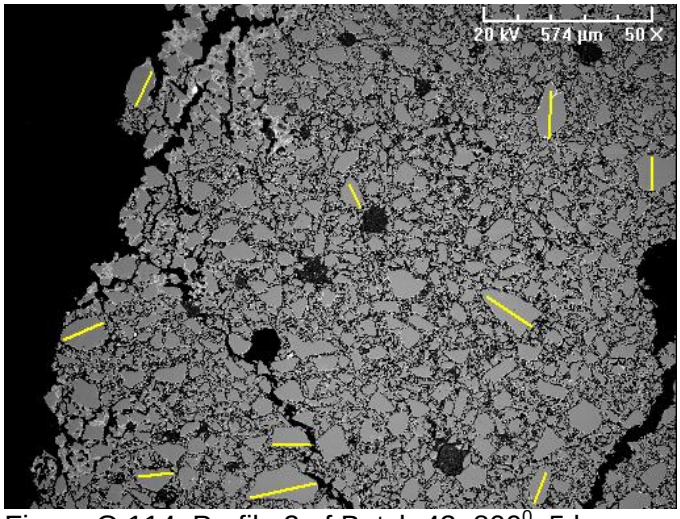


Figure O.114: Profile 2 of Batch 43, 800^0, 5 hr.

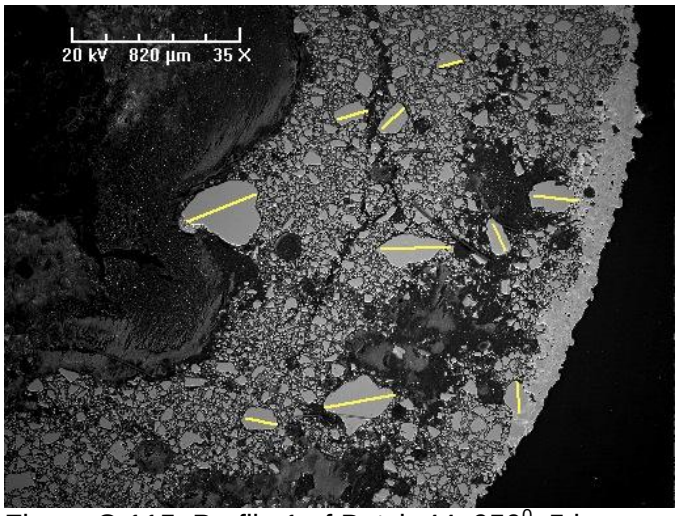


Figure O.115: Profile 1 of Batch 44, 950^0, 5 hr, cementation.

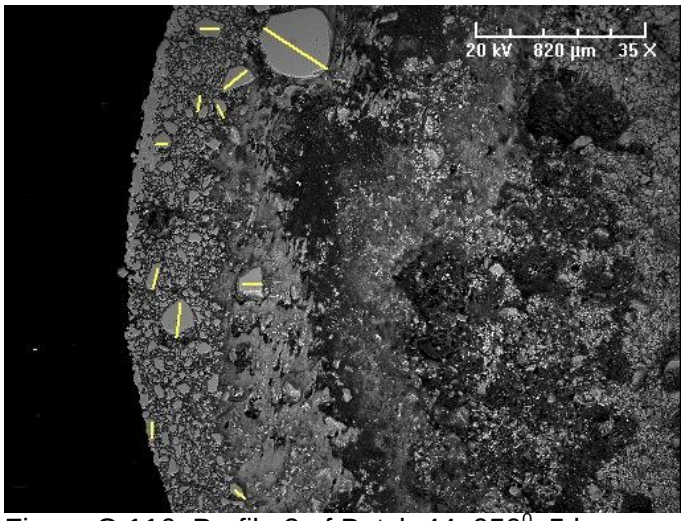


Figure O.116: Profile 2 of Batch 44, 950^0, 5 hr, cementation.

Appendix P: Particle Size Chart

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
MK	54.00.75-1	1	1	132 µm	123 µm	25.4 µm
MK	54.00.75-1	1	2	149 µm		
MK	54.00.75-1	1	3	113 µm		
MK	54.00.75-1	1	4	123 µm		
MK	54.00.75-1	1	5	117 µm		
MK	54.00.75-1	1	6	114 µm		
MK	54.00.75-1	1	7	155 µm		
MK	54.00.75-1	1	8	149 µm		
MK	54.00.75-1	1	9	103 µm		
MK	54.00.75-1	1	10	70.3 µm		
MK	54.00.75-1	2	1	199 µm	130 µm	27.3 µm
MK	54.00.75-1	2	2	128 µm		
MK	54.00.75-1	2	3	134 µm		
MK	54.00.75-1	2	4	130 µm		
MK	54.00.75-1	2	5	137 µm		
MK	54.00.75-1	2	6	104 µm		
MK	54.00.75-1	2	7	126 µm		
MK	54.00.75-1	2	8	102 µm		
MK	54.00.75-1	2	9	129 µm		
MK	54.00.75-1	2	10	109 µm		
MK	54.00.75-2	1	1	128 µm	110 µm	16.9 µm
MK	54.00.75-2	1	2	113 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
MK	54.00.75-2	1	3	116 µm		
MK	54.00.75-2	1	4	122 µm		
MK	54.00.75-2	1	5	118 µm		
MK	54.00.75-2	1	6	128 µm		
MK	54.00.75-2	1	7	102 µm		
MK	54.00.75-2	1	8	108 µm		
MK	54.00.75-2	1	9	74.9 µm		
MK	54.00.75-2	1	10	91.1 µm		
MK	54.00.75-2	2	1	197 µm	125 µm	36.8 µm
MK	54.00.75-2	2	2	165 µm		
MK	54.00.75-2	2	3	136 µm		
MK	54.00.75-2	2	4	136 µm		
MK	54.00.75-2	2	5	125 µm		
MK	54.00.75-2	2	6	80.5 µm		
MK	54.00.75-2	2	7	116 µm		
MK	54.00.75-2	2	8	124 µm		
MK	54.00.75-2	2	9	77.3 µm		
MK	54.00.75-2	2	10	94.9 µm		
MK	54.00.75-3	1	1	171 µm	108 µm	30.2 µm
MK	54.00.75-3	1	2	144 µm		
MK	54.00.75-3	1	3	112 µm		
MK	54.00.75-3	1	4	115 µm		
MK	54.00.75-3	1	5	93.1 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
MK	54.00.75-3	1	6	101 µm		
MK	54.00.75-3	1	7	100 µm		
MK	54.00.75-3	1	8	79.0 µm		
MK	54.00.75-3	1	9	101 µm		
MK	54.00.75-3	1	10	67.4 µm		
MK	54.00.75-3	2	1	102 µm	90.5 µm	18.0 µm
MK	54.00.75-3	2	2	86.7 µm		
MK	54.00.75-3	2	3	94.9 µm		
MK	54.00.75-3	2	4	135 µm		
MK	54.00.75-3	2	5	93.7 µm		
MK	54.00.75-3	2	6	73.0 µm		
MK	54.00.75-3	2	7	83.6 µm		
MK	54.00.75-3	2	8	78.4 µm		
MK	54.00.75-3	2	9	75.6 µm		
MK	54.00.75-3	2	10	82.4 µm		
MK	54.00.75-4	1	1	180 µm	151 µm	46.7 µm
MK	54.00.75-4	1	2	152 µm		
MK	54.00.75-4	1	3	118 µm		
MK	54.00.75-4	1	4	266 µm		
MK	54.00.75-4	1	5	150 µm		
MK	54.00.75-4	1	6	164 µm		
MK	54.00.75-4	1	7	111 µm		
MK	54.00.75-4	1	8	131 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
MK	54.00.75-4	1	9	122 µm		
MK	54.00.75-4	1	10	113 µm		
MK	54.00.75-4	2	1	260 µm	148 µm	49.1 µm
MK	54.00.75-4	2	2	142 µm		
MK	54.00.75-4	2	3	201 µm		
MK	54.00.75-4	2	4	155 µm		
MK	54.00.75-4	2	5	143 µm		
MK	54.00.75-4	2	6	122 µm		
MK	54.00.75-4	2	7	130 µm		
MK	54.00.75-4	2	8	114 µm		
MK	54.00.75-4	2	9	88.8 µm		
MK	54.00.75-4	2	10	121 µm		
MK	54.00.75-5	1	1	307 µm	184 µm	62.5 µm
MK	54.00.75-5	1	2	257 µm		
MK	54.00.75-5	1	3	182 µm		
MK	54.00.75-5	1	4	154 µm		
MK	54.00.75-5	1	5	169 µm		
MK	54.00.75-5	1	6	156 µm		
MK	54.00.75-5	1	7	126 µm		
MK	54.00.75-5	1	8	120 µm		
MK	54.00.75-5	1	9	234 µm		
MK	54.00.75-5	1	10	131 µm		
MK	54.00.75-5	2	1	562 µm	181 µm	136 µm

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
MK	54.00.75-5	2	2	134 µm		
MK	54.00.75-5	2	3	136 µm		
MK	54.00.75-5	2	4	210 µm		
MK	54.00.75-5	2	5	120 µm		
MK	54.00.75-5	2	6	124 µm		
MK	54.00.75-5	2	7	133 µm		
MK	54.00.75-5	2	8	140 µm		
MK	54.00.75-5	2	9	109 µm		
MK	54.00.75-5	2	10	145 µm		
MK	54.00.75-6	1	1	142 µm	110 µm	21.2 µm
MK	54.00.75-6	1	2	146 µm		
MK	54.00.75-6	1	3	97.6 µm		
MK	54.00.75-6	1	4	109 µm		
MK	54.00.75-6	1	5	121 µm		
MK	54.00.75-6	1	6	97.8 µm		
MK	54.00.75-6	1	7	80.2 µm		
MK	54.00.75-6	1	8	107 µm		
MK	54.00.75-6	1	9	102 µm		
MK	54.00.75-6	1	10	92.7 µm		
MK	54.00.75-6	2	1	130 µm	123 µm	28.1 µm
MK	54.00.75-6	2	2	170 µm		
MK	54.00.75-6	2	3	120 µm		
MK	54.00.75-6	2	4	129 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
MK	54.00.75-6	2	5	94.9 µm		
MK	54.00.75-6	2	6	106 µm		
MK	54.00.75-6	2	7	102 µm		
MK	54.00.75-6	2	8	100 µm		
MK	54.00.75-6	2	9	102 µm		
MK	54.00.75-6	2	10	171 µm		
MK	54.00.75-7	1	1	136 µm	124 µm	44.0 µm
MK	54.00.75-7	1	2	203 µm		
MK	54.00.75-7	1	3	122 µm		
MK	54.00.75-7	1	4	159 µm		
MK	54.00.75-7	1	5	177 µm		
MK	54.00.75-7	1	6	87.0 µm		
MK	54.00.75-7	1	7	98.6 µm		
MK	54.00.75-7	1	8	98.6 µm		
MK	54.00.75-7	1	9	93.1 µm		
MK	54.00.75-7	1	10	65.5 µm		
MK	54.00.75-7	2	1	122 µm	99.7 µm	22.2 µm
MK	54.00.75-7	2	2	134 µm		
MK	54.00.75-7	2	3	106 µm		
MK	54.00.75-7	2	4	110 µm		
MK	54.00.75-7	2	5	110 µm		
MK	54.00.75-7	2	6	98.0 µm		
MK	54.00.75-7	2	7	100 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
MK	54.00.75-7	2	8	74.7 µm		
MK	54.00.75-7	2	9	79.8 µm		
MK	54.00.75-7	2	10	61.3 µm		
MK	54.00.75-8	1	1	255 µm	137 µm	49.4 µm
MK	54.00.75-8	1	2	185 µm		
MK	54.00.75-8	1	3	109 µm		
MK	54.00.75-8	1	4	141 µm		
MK	54.00.75-8	1	5	142 µm		
MK	54.00.75-8	1	6	121 µm		
MK	54.00.75-8	1	7	112 µm		
MK	54.00.75-8	1	8	98.8 µm		
MK	54.00.75-8	1	9	113 µm		
MK	54.00.75-8	1	10	91.9 µm		
MK	54.00.75-8	2	1	189 µm	127 µm	34.4 µm
MK	54.00.75-8	2	2	175 µm		
MK	54.00.75-8	2	3	147 µm		
MK	54.00.75-8	2	4	111 µm		
MK	54.00.75-8	2	5	126 µm		
MK	54.00.75-8	2	6	122 µm		
MK	54.00.75-8	2	7	130 µm		
MK	54.00.75-8	2	8	93.5 µm		
MK	54.00.75-8	2	9	90.9 µm		
MK	54.00.75-8	2	10	89.3 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
MK	54.00.75-9	1	1	156 µm	124 µm	19.5 µm
MK	54.00.75-9	1	2	156 µm		
MK	54.00.75-9	1	3	105 µm		
MK	54.00.75-9	1	4	128 µm		
MK	54.00.75-9	1	5	115 µm		
MK	54.00.75-9	1	6	114 µm		
MK	54.00.75-9	1	7	110 µm		
MK	54.00.75-9	1	8	111 µm		
MK	54.00.75-9	1	9	137 µm		
MK	54.00.75-9	1	10	108 µm		
MK	54.00.75-9	2	1	140 µm	117 µm	18.7 µm
MK	54.00.75-9	2	2	130 µm		
MK	54.00.75-9	2	3	118 µm		
MK	54.00.75-9	2	4	142 µm		
MK	54.00.75-9	2	5	95.1 µm		
MK	54.00.75-9	2	6	95.8 µm		
MK	54.00.75-9	2	7	116 µm		
MK	54.00.75-9	2	8	131 µm		
MK	54.00.75-9	2	9	102 µm		
MK	54.00.75-9	2	10	95.7 µm		
MK	54.00.75-10	1	1	125 µm	94.2 µm	24.2 µm
MK	54.00.75-10	1	2	132 µm		
MK	54.00.75-10	1	3	125 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
MK	54.00.75-10	1	4	95.7 µm		
MK	54.00.75-10	1	5	80.4 µm		
MK	54.00.75-10	1	6	85.4 µm		
MK	54.00.75-10	1	7	73.5 µm		
MK	54.00.75-10	1	8	78.2 µm		
MK	54.00.75-10	1	9	82.9 µm		
MK	54.00.75-10	1	10	64.3 µm		
MK	54.00.75-10	2	1	155 µm	78.9 µm	30.3 µm
MK	54.00.75-10	2	2	102 µm		
MK	54.00.75-10	2	3	74.6 µm		
MK	54.00.75-10	2	4	77.3 µm		
MK	54.00.75-10	2	5	59.4 µm		
MK	54.00.75-10	2	6	65.1 µm		
MK	54.00.75-10	2	7	75.7 µm		
MK	54.00.75-10	2	8	46.8 µm		
MK	54.00.75-10	2	9	70.0 µm		
MK	54.00.75-10	2	10	63.1 µm		
MK	2379-1	1	1	204 µm		
MK	2379-1	1	2	146 µm		
MK	2379-1	1	3	124 µm		
MK	2379-1	1	4	121 µm		
MK	2379-1	1	5	115 µm		
MK	2379-1	1	6	129 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
MK	2379-1	1	7	115 µm		
MK	2379-1	1	8	137 µm		
MK	2379-1	1	9	157 µm		
MK	2379-1	1	10	115 µm		
MK	2379-1	2	1	136 µm	118 µm	125 µm
MK	2379-1	2	2	27.7 µm		
MK	2379-1	2	3	210 µm		
MK	2379-1	2	4	152 µm		
MK	2379-1	2	5	191 µm		
MK	2379-1	2	6	133 µm		
MK	2379-1	2	7	140 µm		
MK	2379-1	2	8	131 µm		
MK	2379-1	2	9	115 µm		
MK	2379-1	2	10	119 µm		
MK	2379-2	1	1	282 µm	112 µm	63.4 µm
MK	2379-2	1	2	138 µm		
MK	2379-2	1	3	84.1 µm		
MK	2379-2	1	4	109 µm		
MK	2379-2	1	5	96.0 µm		
MK	2379-2	1	6	106 µm		
MK	2379-2	1	7	65.9 µm		
MK	2379-2	1	8	75.0 µm		
MK	2379-2	1	9	76.5 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
MK	2379-2	1	10	84.9 µm		
MK	2379-2	2	1	158 µm	108 µm	26.0 µm
MK	2379-2	2	2	137 µm		
MK	2379-2	2	3	104 µm		
MK	2379-2	2	4	87.0 µm		
MK	2379-2	2	5	102 µm		
MK	2379-2	2	6	69.1 µm		
MK	2379-2	2	7	109 µm		
MK	2379-2	2	8	82.4 µm		
MK	2379-2	2	9	117 µm		
MK	2379-2	2	10	112 µm		
MK	2379-3	1	1	176 µm	117 µm	34.8 µm
MK	2379-3	1	2	174 µm		
MK	2379-3	1	3	102 µm		
MK	2379-3	1	4	133 µm		
MK	2379-3	1	5	119 µm		
MK	2379-3	1	6	121 µm		
MK	2379-3	1	7	89.1 µm		
MK	2379-3	1	8	80.8 µm		
MK	2379-3	1	9	83.6 µm		
MK	2379-3	1	10	94.9 µm		
MK	2379-3	2	1	93.0 µm	137 µm	124 µm
MK	2379-3	2	2	130 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
MK	2379-3	2	3	132 µm		
MK	2379-3	2	4	83.0 µm		
MK	2379-3	2	5	107 µm		
MK	2379-3	2	6	102 µm		
MK	2379-3	2	7	85.3 µm		
MK	2379-3	2	8	485 µm		
MK	2379-3	2	9	84.9 µm		
MK	2379-3	2	10	67.1 µm		
MK	2379-4	1	1	120 µm	90.8 µm	21.0 µm
MK	2379-4	1	2	84.5 µm		
MK	2379-4	1	3	89.9 µm		
MK	2379-4	1	4	113 µm		
MK	2379-4	1	5	106 µm		
MK	2379-4	1	6	81.9 µm		
MK	2379-4	1	7	62.4 µm		
MK	2379-4	1	8	113 µm		
MK	2379-4	1	9	71.3 µm		
MK	2379-4	1	10	66.4 µm		
MK	2379-4	2	1	114 µm	126 µm	38.9 µm
MK	2379-4	2	2	167 µm		
MK	2379-4	2	3	193 µm		
MK	2379-4	2	4	90.0 µm		
MK	2379-4	2	5	86.5 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
MK	2379-4	2	6	165 µm		
MK	2379-4	2	7	110 µm		
MK	2379-4	2	8	108 µm		
MK	2379-4	2	9	82.5 µm		
MK	2379-4	2	10	148 µm		
MK	2379-5	1	1	166 µm	101 µm	26.4 µm
MK	2379-5	1	2	98.9 µm		
MK	2379-5	1	3	82.1 µm		
MK	2379-5	1	4	74.1 µm		
MK	2379-5	1	5	113 µm		
MK	2379-5	1	6	107 µm		
MK	2379-5	1	7	96.0 µm		
MK	2379-5	1	8	111 µm		
MK	2379-5	1	9	84.1 µm		
MK	2379-5	1	10	80.7 µm		
MK	2379-5	2	1	85.6 µm	77.5 µm	22.1 µm
MK	2379-5	2	2	128 µm		
MK	2379-5	2	3	77.4 µm		
MK	2379-5	2	4	55.0 µm		
MK	2379-5	2	5	61.6 µm		
MK	2379-5	2	6	86.2 µm		
MK	2379-5	2	7	61.8 µm		
MK	2379-5	2	8	82.6 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
MK	2379-5	2	9	86.0 µm		
MK	2379-5	2	10	51.8 µm		
MK	2379-6	1	1	93.2 µm	77.0 µm	22.7 µm
MK	2379-6	1	2	105 µm		
MK	2379-6	1	3	87.7 µm		
MK	2379-6	1	4	116 µm		
MK	2379-6	1	5	75.6 µm		
MK	2379-6	1	6	67.7 µm		
MK	2379-6	1	7	50.5 µm		
MK	2379-6	1	8	60.0 µm		
MK	2379-6	1	9	53.9 µm		
MK	2379-6	1	10	60.0 µm		
MK	2379-6	2	1	64.4 µm	79.5 µm	26.0 µm
MK	2379-6	2	2	145 µm		
MK	2379-6	2	3	76.6 µm		
MK	2379-6	2	4	75.1 µm		
MK	2379-6	2	5	51.2 µm		
MK	2379-6	2	6	57.7 µm		
MK	2379-6	2	7	94.2 µm		
MK	2379-6	2	8	76.2 µm		
MK	2379-6	2	9	83.4 µm		
MK	2379-6	2	10	72.1 µm		
MK	2379-7	1	1	132 µm	127 µm	31.9 µm

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
MK	2379-7	1	2	110 µm		
MK	2379-7	1	3	158 µm		
MK	2379-7	1	4	177 µm		
MK	2379-7	1	5	121 µm		
MK	2379-7	1	6	174 µm		
MK	2379-7	1	7	98.4 µm		
MK	2379-7	1	8	93.2 µm		
MK	2379-7	1	9	101 µm		
MK	2379-7	1	10	106 µm		
MK	2379-7	2	1	117 µm	116 µm	22.3 µm
MK	2379-7	2	2	122 µm		
MK	2379-7	2	3	134 µm		
MK	2379-7	2	4	130 µm		
MK	2379-7	2	5	102 µm		
MK	2379-7	2	6	136 µm		
MK	2379-7	2	7	90.7 µm		
MK	2379-7	2	8	153 µm		
MK	2379-7	2	9	93.0 µm		
MK	2379-7	2	10	87.6 µm		
MK	2379-8	1	1	152 µm	140 µm	57.0 µm
MK	2379-9	1	2	227 µm		
MK	2379-8	1	3	227 µm		
MK	2379-8	1	4	195 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
MK	2379-8	1	5	105 µm		
MK	2379-8	1	6	128 µm		
MK	2379-8	1	7	88.6 µm		
MK	2379-8	1	8	89.9 µm		
MK	2379-8	1	9	95.7 µm		
MK	2379-8	1	10	90.0 µm		
MK	2379-8	2	1	223 µm	132 µm	53.2 µm
MK	2379-8	2	2	225 µm		
MK	2379-8	2	3	84.5 µm		
MK	2379-8	2	4	97.6 µm		
MK	2379-8	2	5	159 µm		
MK	2379-8	2	6	106 µm		
MK	2379-8	2	7	94.2 µm		
MK	2379-8	2	8	102 µm		
MK	2379-8	2	9	128 µm		
MK	2379-8	2	10	96.0 µm		
MK	2379-9	1	1	160 µm	126 µm	31.3 µm
MK	2379-9	1	2	117 µm		
MK	2379-9	1	3	188 µm		
MK	2379-9	1	4	90.7 µm		
MK	2379-9	1	5	127 µm		
MK	2379-9	1	6	153 µm		
MK	2379-9	1	7	103 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
MK	2379-9	1	8	103 µm		
MK	2379-9	1	9	100 µm		
MK	2379-9	1	10	122 µm		
MK	2379-9	2	1	340 µm	127 µm	82.3 µm
MK	2379-9	2	2	181 µm		
MK	2379-9	2	3	84.7 µm		
MK	2379-9	2	4	108 µm		
MK	2379-9	2	5	78.0 µm		
MK	2379-9	2	6	72.1 µm		
MK	2379-9	2	7	77.8 µm		
MK	2379-9	2	8	132 µm		
MK	2379-9	2	9	74.3 µm		
MK	2379-9	2	10	121 µm		
MK	2379-10	1	1	334 µm	248 µm	49.3 µm
MK	2379-10	1	2	293 µm		
MK	2379-10	1	3	260 µm		
MK	2379-10	1	4	219 µm		
MK	2379-10	1	5	311 µm		
MK	2379-10	1	6	234 µm		
MK	2379-10	1	7	185 µm		
MK	2379-10	1	8	209 µm		
MK	2379-10	1	9	223 µm		
MK	2379-10	1	10	214 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
MK	2379-10	2	1	217 µm	193 µm	36.4 µm
MK	2379-10	2	2	164 µm		
MK	2379-10	2	3	180 µm		
MK	2379-10	2	4	223 µm		
MK	2379-10	2	5	255 µm		
MK	2379-10	2	6	214 µm		
MK	2379-10	2	7	152 µm		
MK	2379-10	2	8	158 µm		
MK	2379-10	2	9	217 µm		
MK	2379-10	2	10	152 µm		
NK	2380-1	1	1	292 µm	127 µm	60.9 µm
NK	2380-1	1	2	120 µm		
NK	2380-1	1	3	126 µm		
NK	2380-1	1	4	90.7 µm		
NK	2380-1	1	5	114 µm		
NK	2380-1	1	6	147 µm		
NK	2380-1	1	7	106 µm		
NK	2380-1	1	8	77.2 µm		
NK	2380-1	1	9	99.0 µm		
NK	2380-1	1	10	101 µm		
NK	2380-1	2	1	212 µm	115 µm	39.0 µm
NK	2380-1	2	2	137 µm		
NK	2380-1	2	3	83.5 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
NK	2380-1	2	4	104 µm		
NK	2380-1	2	5	96.5 µm		
NK	2380-1	2	6	117 µm		
NK	2380-1	2	7	95.9 µm		
NK	2380-1	2	8	76.6 µm		
NK	2380-1	2	9	131 µm		
NK	2380-1	2	10	100 µm		
NK	2380-2	1	1	114 µm	115 µm	40.8 µm
NK	2380-2	1	2	225 µm		
NK	2380-2	1	3	122 µm		
NK	2380-2	1	4	110 µm		
NK	2380-2	1	5	94.0 µm		
NK	2380-2	1	6	99.0 µm		
NK	2380-2	1	7	93.7 µm		
NK	2380-2	1	8	76.0 µm		
NK	2380-2	1	9	110 µm		
NK	2380-2	1	10	102 µm		
NK	2380-2	2	1	130 µm	111 µm	18.4 µm
NK	2380-2	2	2	98.5 µm		
NK	2380-2	2	3	100 µm		
NK	2380-2	2	4	115 µm		
NK	2380-2	2	5	94.8 µm		
NK	2380-2	2	6	116 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
NK	2380-2	2	7	103 µm		
NK	2380-2	2	8	117 µm		
NK	2380-2	2	9	88.4 µm		
NK	2380-2	2	10	149 µm		
NK	2380-3	1	1	119 µm	124 µm	42.2 µm
NK	2380-3	1	2	142 µm		
NK	2380-3	1	3	231 µm		
NK	2380-3	1	4	136 µm		
NK	2380-3	1	5	114 µm		
NK	2380-3	1	6	128 µm		
NK	2380-3	1	7	89.9 µm		
NK	2380-3	1	8	93.7 µm		
NK	2380-3	1	9	95.4 µm		
NK	2380-3	1	10	91.2 µm		
NK	2380-3	2	1	152 µm	126 µm	32.7 µm
NK	2380-3	2	2	184 µm		
NK	2380-3	2	3	166 µm		
NK	2380-3	2	4	122 µm		
NK	2380-3	2	5	124 µm		
NK	2380-3	2	6	117 µm		
NK	2380-3	2	7	82.0 µm		
NK	2380-3	2	8	92.2 µm		
NK	2380-3	2	9	125 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
NK	2380-3	2	10	97.5 µm		
NK	2380-4	1	1	128 µm	123 µm	32.6 µm
NK	2380-4	1	2	110 µm		
NK	2380-4	1	3	128 µm		
NK	2380-4	1	4	180 µm		
NK	2380-4	1	5	179 µm		
NK	2380-4	1	6	116 µm		
NK	2380-4	1	7	96.8 µm		
NK	2380-4	1	8	91.6 µm		
NK	2380-4	1	9	87.2 µm		
NK	2380-4	1	10	118 µm		
NK	2380-4	2	1	157 µm	120 µm	29.0 µm
NK	2380-4	2	2	173 µm		
NK	2380-4	2	3	126 µm		
NK	2380-4	2	4	99.0 µm		
NK	2380-4	2	5	106 µm		
NK	2380-4	2	6	141 µm		
NK	2380-4	2	7	105 µm		
NK	2380-4	2	8	117 µm		
NK	2380-4	2	9	93.4 µm		
NK	2380-4	2	10	83.5 µm		
NK	2380-5	1	1	79.6 µm	95.6 µm	28.2 µm
NK	2380-5	1	2	126 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
NK	2380-5	1	3	125 µm		
NK	2380-5	1	4	128 µm		
NK	2380-5	1	5	102 µm		
NK	2380-5	1	6	122 µm		
NK	2380-5	1	7	66.5 µm		
NK	2380-5	1	8	70.9 µm		
NK	2380-5	1	9	54.0 µm		
NK	2380-5	1	10	82.2 µm		
NK	2380-5	2	1	265 µm	111 µm	55.1 µm
NK	2380-5	2	2	101 µm		
NK	2380-5	2	3	111 µm		
NK	2380-5	2	4	93.0 µm		
NK	2380-5	2	5	107 µm		
NK	2380-5	2	6	86.2 µm		
NK	2380-5	2	7	78.8 µm		
NK	2380-5	2	8	83.8 µm		
NK	2380-5	2	9	108 µm		
NK	2380-5	2	10	80.9 µm		
NK	2380-6	1	1	93.5 µm	103 µm	20.5 µm
NK	2380-6	1	2	111 µm		
NK	2380-6	1	3	99.3 µm		
NK	2380-6	1	4	148 µm		
NK	2380-6	1	5	108 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
NK	2380-6	1	6	72.1 µm		
NK	2380-6	1	7	116 µm		
NK	2380-6	1	8	82.0 µm		
NK	2380-6	1	9	103 µm		
NK	2380-6	1	10	99.0 µm		
NK	2380-6	2	1	160 µm	123 µm	35.5 µm
NK	2380-6	2	2	163 µm		
NK	2380-6	2	3	134 µm		
NK	2380-6	2	4	184 µm		
NK	2380-6	2	5	120 µm		
NK	2380-6	2	6	104 µm		
NK	2380-6	2	7	99.3 µm		
NK	2380-6	2	8	80.6 µm		
NK	2380-6	2	9	85.9 µm		
NK	2380-6	2	10	100.0 µm		
NK	2380-7	1	1	188 µm	132 µm	38.9 µm
NK	2380-7	1	2	161 µm		
NK	2380-7	1	3	120 µm		
NK	2380-7	1	4	139 µm		
NK	2380-7	1	5	195 µm		
NK	2380-7	1	6	107 µm		
NK	2380-7	1	7	104 µm		
NK	2380-7	1	8	131 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
NK	2380-7	1	9	86.2 µm		
NK	2380-7	1	10	86.0 µm		
NK	2380-7	2	1	276 µm	166 µm	65.8 µm
NK	2380-7	2	2	140 µm		
NK	2380-7	2	3	283 µm		
NK	2380-7	2	4	164 µm		
NK	2380-7	2	5	191 µm		
NK	2380-7	2	6	145 µm		
NK	2380-7	2	7	134 µm		
NK	2380-7	2	8	128 µm		
NK	2380-7	2	9	106 µm		
NK	2380-7	2	10	93.3 µm		
NK	2380-8	1	1	110 µm	73.8 µm	22.4 µm
NK	2380-8	1	2	84.2 µm		
NK	2380-8	1	3	92.1 µm		
NK	2380-8	1	4	55.3 µm		
NK	2380-8	1	5	71.6 µm		
NK	2380-8	1	6	102 µm		
NK	2380-8	1	7	47.5 µm		
NK	2380-8	1	8	69.1 µm		
NK	2380-8	1	9	52.8 µm		
NK	2380-8	1	10	53.0 µm		
NK	2380-8	2	1	226 µm	118 µm	42.7 µm

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
NK	2380-8	2	2	140 µm		
NK	2380-8	2	3	96.0 µm		
NK	2380-8	2	4	118 µm		
NK	2380-8	2	5	103 µm		
NK	2380-8	2	6	103 µm		
NK	2380-8	2	7	92.0 µm		
NK	2380-8	2	8	127 µm		
NK	2380-8	2	9	70.3 µm		
NK	2380-8	2	10	101 µm		
NK	2380-9	1	1	139 µm	127 µm	32.9 µm
NK	2380-9	1	2	165 µm		
NK	2380-9	1	3	108 µm		
NK	2380-9	1	4	166 µm		
NK	2380-9	1	5	90.8 µm		
NK	2380-9	1	6	115 µm		
NK	2380-9	1	7	96.9 µm		
NK	2380-9	1	8	79.9 µm		
NK	2380-9	1	9	167 µm		
NK	2380-9	1	10	141 µm		
NK	2380-9	2	1	166 µm	130 µm	64.4 µm
NK	2380-9	2	2	290 µm		
NK	2380-9	2	3	128 µm		
NK	2380-9	2	4	158 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
NK	2380-9	2	5	119 µm		
NK	2380-9	2	6	105 µm		
NK	2380-9	2	7	87.2 µm		
NK	2380-9	2	8	95.5 µm		
NK	2380-9	2	9	76.2 µm		
NK	2380-9	2	10	75.4 µm		
NK	2380-10	1	1	113 µm	122 µm	28.9 µm
NK	2380-10	1	2	140 µm		
NK	2380-10	1	3	166 µm		
NK	2380-10	1	4	128 µm		
NK	2380-10	1	5	157 µm		
NK	2380-10	1	6	102 µm		
NK	2380-10	1	7	109 µm		
NK	2380-10	1	8	136 µm		
NK	2380-10	1	9	83.4 µm		
NK	2380-10	1	10	81.2 µm		
NK	2380-10	2	1	191 µm	146 µm	37.0 µm
NK	2380-10	2	2	200 µm		
NK	2380-10	2	3	145 µm		
NK	2380-10	2	4	185 µm		
NK	2380-10	2	5	120 µm		
NK	2380-10	2	6	163 µm		
NK	2380-10	2	7	137 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
NK	2380-10	2	8	117 µm		
NK	2380-10	2	9	100 µm		
NK	2380-10	2	10	103 µm		
NK	4075-1	1	1	93.6 µm	69.8 µm	23.1 µm
NK	4075-1	1	2	85.1 µm		
NK	4075-1	1	3	61.2 µm		
NK	4075-1	1	4	44.7 µm		
NK	4075-1	1	5	119 µm		
NK	4075-1	1	6	68.4 µm		
NK	4075-1	1	7	62.2 µm		
NK	4075-1	1	8	50.4 µm		
NK	4075-1	1	9	63.1 µm		
NK	4075-1	1	10	50.4 µm		
NK	4075-1	2	1	103 µm	103 µm	29.0 µm
NK	4075-1	2	2	154 µm		
NK	4075-1	2	3	97.7 µm		
NK	4075-1	2	4	153 µm		
NK	4075-1	2	5	87.0 µm		
NK	4075-1	2	6	74.5 µm		
NK	4075-1	2	7	92.1 µm		
NK	4075-1	2	8	81.3 µm		
NK	4075-1	2	9	75.2 µm		
NK	4075-1	2	10	108 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
NK	4075-2	1	1	374 µm	239 µm	74.8 µm
NK	4075-2	1	2	319 µm		
NK	4075-2	1	3	261 µm		
NK	4075-2	1	4	248 µm		
NK	4075-2	1	5	298 µm		
NK	4075-2	1	6	188 µm		
NK	4075-2	1	7	208 µm		
NK	4075-2	1	8	197 µm		
NK	4075-2	1	9	140 µm		
NK	4075-2	1	10	157 µm		
NK	4075-2	2	1	166 µm	155 µm	47.7 µm
NK	4075-2	2	2	251 µm		
NK	4075-2	2	3	189 µm		
NK	4075-2	2	4	175 µm		
NK	4075-2	2	5	148 µm		
NK	4075-2	2	6	116 µm		
NK	4075-2	2	7	107 µm		
NK	4075-2	2	8	103 µm		
NK	4075-2	2	9	183 µm		
NK	4075-2	2	10	107 µm		
NK	4075-3	1	1	146 µm	86.2 µm	22.7 µm
NK	4075-3	1	2	94.0 µm		
NK	4075-3	1	3	78.4 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
NK	4075-3	1	4	78.4 µm		
NK	4075-3	1	5	72.5 µm		
NK	4075-3	1	6	86.0 µm		
NK	4075-3	1	7	71.6 µm		
NK	4075-3	1	8	91.1 µm		
NK	4075-3	1	9	68.3 µm		
NK	4075-3	1	10	75.5 µm		
NK	4075-3	2	1	122 µm	94.1 µm	25.9 µm
NK	4075-3	2	2	100 µm		
NK	4075-3	2	3	125 µm		
NK	4075-3	2	4	135 µm		
NK	4075-3	2	5	86.1 µm		
NK	4075-3	2	6	80.6 µm		
NK	4075-3	2	7	90.0 µm		
NK	4075-3	2	8	56.9 µm		
NK	4075-3	2	9	74.2 µm		
NK	4075-3	2	10	70.8 µm		
NK	4075-4	1	1	99.6 µm	76.3 µm	12.2 µm
NK	4075-4	1	2	71.6 µm		
NK	4075-4	1	3	91.3 µm		
NK	4075-4	1	4	84.4 µm		
NK	4075-4	1	5	66.0 µm		
NK	4075-4	1	6	74.2 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
NK	4075-4	1	7	63.2 µm		
NK	4075-4	1	8	63.5 µm		
NK	4075-4	1	9	77.8 µm		
NK	4075-4	1	10	71.2 µm		
NK	4075-4	2	1	187 µm	85.9 µm	43.5 µm
NK	4075-4	2	2	130 µm		
NK	4075-4	2	3	97.0 µm		
NK	4075-4	2	4	88.6 µm		
NK	4075-4	2	5	61.7 µm		
NK	4075-4	2	6	68.0 µm		
NK	4075-4	2	7	62.5 µm		
NK	4075-4	2	8	71.5 µm		
NK	4075-4	2	9	52.0 µm		
NK	4075-4	2	10	41.2 µm		
NK	4075-5	1	1	94.8 µm	91.7 µm	14.4 µm
NK	4075-5	1	2	105 µm		
NK	4075-5	1	3	82.5 µm		
NK	4075-5	1	4	73.2 µm		
NK	4075-5	1	5	75.1 µm		
NK	4075-5	1	6	98.5 µm		
NK	4075-5	1	7	81.4 µm		
NK	4075-5	1	8	90.0 µm		
NK	4075-5	1	9	96.9 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
NK	4075-5	1	10	120 µm		
NK	4075-5	2	1	90.0 µm	91.9 µm	30.6 µm
NK	4075-5	2	2	64.4 µm		
NK	4075-5	2	3	142 µm		
NK	4075-5	2	4	67.2 µm		
NK	4075-5	2	5	146 µm		
NK	4075-5	2	6	90.6 µm		
NK	4075-5	2	7	55.6 µm		
NK	4075-5	2	8	79.9 µm		
NK	4075-5	2	9	99.9 µm		
NK	4075-5	2	10	82.9 µm		
SIP	2385-1	1	1	242 µm	205 µm	38.7 µm
SIP	2385-1	1	2	234 µm		
SIP	2385-1	1	3	255 µm		
SIP	2385-1	1	4	226 µm		
SIP	2385-1	1	5	201 µm		
SIP	2385-1	1	6	197 µm		
SIP	2385-1	1	7	229 µm		
SIP	2385-1	1	8	166 µm		
SIP	2385-1	1	9	137 µm		
SIP	2385-1	1	10	167 µm		
SIP	2385-1	2	1	165 µm	186 µm	46.7 µm
SIP	2385-1	2	2	221 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
SIP	2385-1	2	3	169 µm		
SIP	2385-1	2	4	272 µm		
SIP	2385-1	2	5	237 µm		
SIP	2385-1	2	6	137 µm		
SIP	2385-1	2	7	142 µm		
SIP	2385-1	2	8	149 µm		
SIP	2385-1	2	9	152 µm		
SIP	2385-1	2	10	211 µm		
SIP	2385-2	1	1	161 µm	122 µm	27.0 µm
SIP	2385-2	1	2	152 µm		
SIP	2385-2	1	3	105 µm		
SIP	2385-2	1	4	142 µm		
SIP	2385-2	1	5	101 µm		
SIP	2385-2	1	6	142 µm		
SIP	2385-2	1	7	120 µm		
SIP	2385-2	1	8	91.8 µm		
SIP	2385-2	1	9	121 µm		
SIP	2385-2	1	10	81.1 µm		
SIP	2385-2	2	1	223 µm	135 µm	39.0 µm
SIP	2385-2	2	2	157 µm		
SIP	2385-2	2	3	124 µm		
SIP	2385-2	2	4	164 µm		
SIP	2385-2	2	5	119 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
SIP	2385-2	2	6	128 µm		
SIP	2385-2	2	7	84.2 µm		
SIP	2385-2	2	8	117 µm		
SIP	2385-2	2	9	98.4 µm		
SIP	2385-2	2	10	134 µm		
SIP	2385-3	1	1	139 µm	112 µm	21.5 µm
SIP	2385-3	1	2	138 µm		
SIP	2385-3	1	3	117 µm		
SIP	2385-3	1	4	95.7 µm		
SIP	2385-3	1	5	141 µm		
SIP	2385-3	1	6	103 µm		
SIP	2385-3	1	7	91.2 µm		
SIP	2385-3	1	8	113 µm		
SIP	2385-3	1	9	79.9 µm		
SIP	2385-3	1	10	101 µm		
SIP	2385-3	2	1	157 µm	114 µm	22.9 µm
SIP	2385-3	2	2	132 µm		
SIP	2385-3	2	3	137 µm		
SIP	2385-3	2	4	99.4 µm		
SIP	2385-3	2	5	98.7 µm		
SIP	2385-3	2	6	100 µm		
SIP	2385-3	2	7	94.2 µm		
SIP	2385-3	2	8	93.8 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
SIP	2385-3	2	9	131 µm		
SIP	2385-3	2	10	97.9 µm		
SIP	2385-4	1	1	50.0 µm	53.9 µm	18.8 µm
SIP	2385-4	1	2	55.6 µm		
SIP	2385-4	1	3	56.6 µm		
SIP	2385-4	1	4	55.8 µm		
SIP	2385-4	1	5	102 µm		
SIP	2385-4	1	6	55.7 µm		
SIP	2385-4	1	7	48.2 µm		
SIP	2385-4	1	8	42.9 µm		
SIP	2385-4	1	9	36.1 µm		
SIP	2385-4	1	10	35.8 µm		
SIP	2385-4	2	1	81.2 µm	42.6 µm	21.1 µm
SIP	2385-4	2	2	78.2 µm		
SIP	2385-4	2	3	43.9 µm		
SIP	2385-4	2	4	34.0 µm		
SIP	2385-4	2	5	22.1 µm		
SIP	2385-4	2	6	37.2 µm		
SIP	2385-4	2	7	26.0 µm		
SIP	2385-4	2	8	40.0 µm		
SIP	2385-4	2	9	42.2 µm		
SIP	2385-4	2	10	21.6 µm		
SIP	2385-5	1	1	54.7 µm	54.9 µm	14.7 µm

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
SIP	2385-5	1	2	66.0 µm		
SIP	2385-5	1	3	81.5 µm		
SIP	2385-5	1	4	40.8 µm		
SIP	2385-5	1	5	55.2 µm		
SIP	2385-5	1	6	49.7 µm		
SIP	2385-5	1	7	33.0 µm		
SIP	2385-5	1	8	59.1 µm		
SIP	2385-5	1	9	40.8 µm		
SIP	2385-5	1	10	68.4 µm		
SIP	2385-5	2	1	55.3 µm	72.7 µm	42.8 µm
SIP	2385-5	2	2	83.0 µm		
SIP	2385-5	2	3	61.8 µm		
SIP	2385-5	2	4	37.6 µm		
SIP	2385-5	2	5	34.2 µm		
SIP	2385-5	2	6	60.7 µm		
SIP	2385-5	2	7	132 µm		
SIP	2385-5	2	8	164 µm		
SIP	2385-5	2	9	48.4 µm		
SIP	2385-5	2	10	49.5 µm		
SIP	2385-6	1	1	48.0 µm	47.7 µm	10.3 µm
SIP	2385-6	1	2	58.2 µm		
SIP	2385-6	1	3	45.0 µm		
SIP	2385-6	1	4	33.1 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
SIP	2385-6	1	5	58.9 µm		
SIP	2385-6	1	6	31.9 µm		
SIP	2385-6	1	7	45.0 µm		
SIP	2385-6	1	8	54.3 µm		
SIP	2385-6	1	9	60.4 µm		
SIP	2385-6	1	10	42.0 µm		
SIP	2385-6	2	1	90.2 µm	65.4 µm	19.6 µm
SIP	2385-6	2	2	61.6 µm		
SIP	2385-6	2	3	49.7 µm		
SIP	2385-6	2	4	55.8 µm		
SIP	2385-6	2	5	74.1 µm		
SIP	2385-6	2	6	84.0 µm		
SIP	2385-6	2	7	58.9 µm		
SIP	2385-6	2	8	95.7 µm		
SIP	2385-6	2	9	45.4 µm		
SIP	2385-6	2	10	39.0 µm		
SIP	2385-7	1	1	109 µm	75.0 µm	20.6 µm
SIP	2385-7	1	2	64.6 µm		
SIP	2385-7	1	3	76.5 µm		
SIP	2385-7	1	4	83.4 µm		
SIP	2385-7	1	5	55.2 µm		
SIP	2385-7	1	6	68.0 µm		
SIP	2385-7	1	7	84.1 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
SIP	2385-7	1	8	103 µm		
SIP	2385-7	1	9	61.8 µm		
SIP	2385-7	1	10	43.7 µm		
SIP	2385-7	2	1	80.5 µm	63.5 µm	11.2 µm
SIP	2385-7	2	2	69.1 µm		
SIP	2385-7	2	3	51.8 µm		
SIP	2385-7	2	4	62.4 µm		
SIP	2385-7	2	5	61.6 µm		
SIP	2385-7	2	6	71.1 µm		
SIP	2385-7	2	7	76.9 µm		
SIP	2385-7	2	8	53.7 µm		
SIP	2385-7	2	9	45.0 µm		
SIP	2385-7	2	10	63.3 µm		
SIP	2385-8	1	1	99.0 µm	68.9 µm	24.2 µm
SIP	2385-8	1	2	56.9 µm		
SIP	2385-8	1	3	102 µm		
SIP	2385-8	1	4	76.7 µm		
SIP	2385-8	1	5	39.0 µm		
SIP	2385-8	1	6	99.0 µm		
SIP	2385-8	1	7	69.0 µm		
SIP	2385-8	1	8	55.8 µm		
SIP	2385-8	1	9	43.3 µm		
SIP	2385-8	1	10	48.0 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
SIP	2385-8	2	1	47.4 µm	52.0 µm	17.6 µm
SIP	2385-8	2	2	74.5 µm		
SIP	2385-8	2	3	78.0 µm		
SIP	2385-8	2	4	44.6 µm		
SIP	2385-8	2	5	27.7 µm		
SIP	2385-8	2	6	36.1 µm		
SIP	2385-8	2	7	68.0 µm		
SIP	2385-8	2	8	42.0 µm		
SIP	2385-8	2	9	38.4 µm		
SIP	2385-8	2	10	63.6 µm		
SIP	2385-9	1	1	58.9 µm	46.1 µm	13.3 µm
SIP	2385-9	1	2	59.8 µm		
SIP	2385-9	1	3	63.3 µm		
SIP	2385-9	1	4	38.2 µm		
SIP	2385-9	1	5	51.0 µm		
SIP	2385-9	1	6	45.1 µm		
SIP	2385-9	1	7	53.4 µm		
SIP	2385-9	1	8	38.2 µm		
SIP	2385-9	1	9	27.7 µm		
SIP	2385-9	1	10	25.8 µm		
SIP	2385-9	2	1	90.0 µm	69.2 µm	25.4 µm
SIP	2385-9	2	2	104 µm		
SIP	2385-9	2	3	107 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
SIP	2385-9	2	4	71.3 µm		
SIP	2385-9	2	5	53.1 µm		
SIP	2385-9	2	6	39.0 µm		
SIP	2385-9	2	7	59.5 µm		
SIP	2385-9	2	8	81.9 µm		
SIP	2385-9	2	9	45.0 µm		
SIP	2385-9	2	10	41.7 µm		
SIP	2385-10	1	1	63.1 µm	64.4 µm	15.4 µm
SIP	2385-10	1	2	81.5 µm		
SIP	2385-10	1	3	63.1 µm		
SIP	2385-10	1	4	79.2 µm		
SIP	2385-10	1	5	73.8 µm		
SIP	2385-10	1	6	46.9 µm		
SIP	2385-10	1	7	59.2 µm		
SIP	2385-10	1	8	79.9 µm		
SIP	2385-10	1	9	63.6 µm		
SIP	2385-10	1	10	33.5 µm		
SIP	2385-10	2	1	61.8 µm	64.0 µm	12.8 µm
SIP	2385-10	2	2	85.0 µm		
SIP	2385-10	2	3	81.6 µm		
SIP	2385-10	2	4	77.4 µm		
SIP	2385-10	2	5	55.3 µm		
SIP	2385-10	2	6	57.9 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
SIP	2385-10	2	7	48.4 µm		
SIP	2385-10	2	8	60.7 µm		
SIP	2385-10	2	9	61.2 µm		
SIP	2385-10	2	10	51.1 µm		
Experiment	Batch 15	1	1	471 µm	304 µm	67.2 µm
Experiment	Batch 15	1	2	280 µm		
Experiment	Batch 15	1	3	306 µm		
Experiment	Batch 15	1	4	288 µm		
Experiment	Batch 15	1	5	272 µm		
Experiment	Batch 15	1	6	273 µm		
Experiment	Batch 15	1	7	341 µm		
Experiment	Batch 15	1	8	316 µm		
Experiment	Batch 15	1	9	273 µm		
Experiment	Batch 15	1	10	219 µm		
Experiment	Batch 15	2	1	405 µm	303 µm	63.7 µm
Experiment	Batch 15	2	2	326 µm		
Experiment	Batch 15	2	3	264 µm		
Experiment	Batch 15	2	4	241 µm		
Experiment	Batch 15	2	5	273 µm		
Experiment	Batch 15	2	6	407 µm		
Experiment	Batch 15	2	7	280 µm		
Experiment	Batch 15	2	8	220 µm		
Experiment	Batch 15	2	9	286 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
Experiment	Batch 15	2	10	330 µm		
Experiment	Batch 17	1	1	377 µm	304 µm	53.6 µm
Experiment	Batch 17	1	2	407 µm		
Experiment	Batch 17	1	3	290 µm		
Experiment	Batch 17	1	4	316 µm		
Experiment	Batch 17	1	5	311 µm		
Experiment	Batch 17	1	6	284 µm		
Experiment	Batch 17	1	7	273 µm		
Experiment	Batch 17	1	8	266 µm		
Experiment	Batch 17	1	9	291 µm		
Experiment	Batch 17	1	10	223 µm		
Experiment	Batch 17	2	1	273 µm	291 µm	35.3 µm
Experiment	Batch 17	2	2	342 µm		
Experiment	Batch 17	2	3	250 µm		
Experiment	Batch 17	2	4	309 µm		
Experiment	Batch 17	2	5	296 µm		
Experiment	Batch 17	2	6	302 µm		
Experiment	Batch 17	2	7	240 µm		
Experiment	Batch 17	2	8	327 µm		
Experiment	Batch 17	2	9	320 µm		
Experiment	Batch 17	2	10	254 µm		
Experiment	Batch 19	1	1	572 µm	358 µm	83.4 µm
Experiment	Batch 19	1	2	392 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
Experiment	Batch 19	1	3	355 µm		
Experiment	Batch 19	1	4	326 µm		
Experiment	Batch 19	1	5	328 µm		
Experiment	Batch 19	1	6	273 µm		
Experiment	Batch 19	1	7	347 µm		
Experiment	Batch 19	1	8	279 µm		
Experiment	Batch 19	1	9	341 µm		
Experiment	Batch 19	1	10	368 µm		
Experiment	Batch 19	2	1	438 µm	334 µm	56.6 µm
Experiment	Batch 19	2	2	364 µm		
Experiment	Batch 19	2	3	364 µm		
Experiment	Batch 19	2	4	316 µm		
Experiment	Batch 19	2	5	383 µm		
Experiment	Batch 19	2	6	247 µm		
Experiment	Batch 19	2	7	263 µm		
Experiment	Batch 19	2	8	342 µm		
Experiment	Batch 19	2	9	311 µm		
Experiment	Batch 19	2	10	315 µm		
Experiment	Batch 26	1	1	217 µm	168 µm	36.3 µm
Experiment	Batch 26	1	2	158 µm		
Experiment	Batch 26	1	3	192 µm		
Experiment	Batch 26	1	4	135 µm		
Experiment	Batch 26	1	5	225 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
Experiment	Batch 26	1	6	180 µm		
Experiment	Batch 26	1	7	142 µm		
Experiment	Batch 26	1	8	159 µm		
Experiment	Batch 26	1	9	159 µm		
Experiment	Batch 26	1	10	109 µm		
Experiment	Batch 26	2	1	223 µm	161 µm	25.9 µm
Experiment	Batch 26	2	2	168 µm		
Experiment	Batch 26	2	3	184 µm		
Experiment	Batch 26	2	4	146 µm		
Experiment	Batch 26	2	5	137 µm		
Experiment	Batch 26	2	6	154 µm		
Experiment	Batch 26	2	7	145 µm		
Experiment	Batch 26	2	8	157 µm		
Experiment	Batch 26	2	9	160 µm		
Experiment	Batch 26	2	10	137 µm		
Experiment	Batch 35	1	1	267 µm	212 µm	29.8 µm
Experiment	Batch 35	1	2	206 µm		
Experiment	Batch 35	1	3	198 µm		
Experiment	Batch 35	1	4	224 µm		
Experiment	Batch 35	1	5	223 µm		
Experiment	Batch 35	1	6	211 µm		
Experiment	Batch 35	1	7	241 µm		
Experiment	Batch 35	1	8	182 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
Experiment	Batch 35	1	9	161 µm		
Experiment	Batch 35	1	10	202 µm		
Experiment	Batch 35	2	1	275 µm	202 µm	43.4 µm
Experiment	Batch 35	2	2	154 µm		
Experiment	Batch 35	2	3	216 µm		
Experiment	Batch 35	2	4	160 µm		
Experiment	Batch 35	2	5	203 µm		
Experiment	Batch 35	2	6	258 µm		
Experiment	Batch 35	2	7	218 µm		
Experiment	Batch 35	2	8	198 µm		
Experiment	Batch 35	2	9	200 µm		
Experiment	Batch 35	2	10	138 µm		
Experiment	Batch 36	1	1	196 µm	187 µm	17.0 µm
Experiment	Batch 36	1	2	220 µm		
Experiment	Batch 36	1	3	197 µm		
Experiment	Batch 36	1	4	182 µm		
Experiment	Batch 36	1	5	187 µm		
Experiment	Batch 36	1	6	190 µm		
Experiment	Batch 36	1	7	189 µm		
Experiment	Batch 36	1	8	181 µm		
Experiment	Batch 36	1	9	156 µm		
Experiment	Batch 36	1	10	169 µm		
Experiment	Batch 36	2	1	224 µm	197 µm	15.6 µm

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
Experiment	Batch 36	2	2	206 µm		
Experiment	Batch 36	2	3	213 µm		
Experiment	Batch 36	2	4	213 µm		
Experiment	Batch 36	2	5	182 µm		
Experiment	Batch 36	2	6	187 µm		
Experiment	Batch 36	2	7	183 µm		
Experiment	Batch 36	2	8	192 µm		
Experiment	Batch 36	2	9	182 µm		
Experiment	Batch 36	2	10	189 µm		
Experiment	Batch 38	1	1	207 µm	166 µm	23.0 µm
Experiment	Batch 38	1	2	174 µm		
Experiment	Batch 38	1	3	170 µm		
Experiment	Batch 38	1	4	133 µm		
Experiment	Batch 38	1	5	165 µm		
Experiment	Batch 38	1	6	163 µm		
Experiment	Batch 38	1	7	188 µm		
Experiment	Batch 38	1	8	132 µm		
Experiment	Batch 38	1	9	151 µm		
Experiment	Batch 38	1	10	176 µm		
Experiment	Batch 38	2	1	187 µm	168 µm	24.5 µm
Experiment	Batch 38	2	2	206 µm		
Experiment	Batch 38	2	3	157 µm		
Experiment	Batch 38	2	4	163 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
Experiment	Batch 38	2	5	168 µm		
Experiment	Batch 38	2	6	153 µm		
Experiment	Batch 38	2	7	128 µm		
Experiment	Batch 38	2	8	206 µm		
Experiment	Batch 38	2	9	157 µm		
Experiment	Batch 38	2	10	157 µm		
Experiment	Batch 39	1	1	164 µm	137 µm	21.9 µm
Experiment	Batch 39	1	2	166 µm		
Experiment	Batch 39	1	3	114 µm		
Experiment	Batch 39	1	4	141 µm		
Experiment	Batch 39	1	5	158 µm		
Experiment	Batch 39	1	6	119 µm		
Experiment	Batch 39	1	7	113 µm		
Experiment	Batch 39	1	8	153 µm		
Experiment	Batch 39	1	9	115 µm		
Experiment	Batch 39	1	10	124 µm		
Experiment	Batch 39	2	1	179 µm	152 µm	31.4 µm
Experiment	Batch 39	2	2	227 µm		
Experiment	Batch 39	2	3	137 µm		
Experiment	Batch 39	2	4	156 µm		
Experiment	Batch 39	2	5	150 µm		
Experiment	Batch 39	2	6	129 µm		
Experiment	Batch 39	2	7	125 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
Experiment	Batch 39	2	8	134 µm		
Experiment	Batch 39	2	9	126 µm		
Experiment	Batch 39	2	10	153 µm		
Experiment	Batch 40	1	1	164 µm	159 µm	46.8 µm
Experiment	Batch 40	1	2	271 µm		
Experiment	Batch 40	1	3	183 µm		
Experiment	Batch 40	1	4	171 µm		
Experiment	Batch 40	1	5	166 µm		
Experiment	Batch 40	1	6	144 µm		
Experiment	Batch 40	1	7	111 µm		
Experiment	Batch 40	1	8	106 µm		
Experiment	Batch 40	1	9	146 µm		
Experiment	Batch 40	1	10	130 µm		
Experiment	Batch 40	2	1	223 µm	184 µm	41.6 µm
Experiment	Batch 40	2	2	235 µm		
Experiment	Batch 40	2	3	118 µm		
Experiment	Batch 40	2	4	155 µm		
Experiment	Batch 40	2	5	213 µm		
Experiment	Batch 40	2	6	206 µm		
Experiment	Batch 40	2	7	199 µm		
Experiment	Batch 40	2	8	119 µm		
Experiment	Batch 40	2	9	171 µm		
Experiment	Batch 40	2	10	200 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
Experiment	Batch 41	1	1	299 µm	212 µm	45.3 µm
Experiment	Batch 41	1	2	157 µm		
Experiment	Batch 41	1	3	244 µm		
Experiment	Batch 41	1	4	206 µm		
Experiment	Batch 41	1	5	257 µm		
Experiment	Batch 41	1	6	198 µm		
Experiment	Batch 41	1	7	167 µm		
Experiment	Batch 41	1	8	182 µm		
Experiment	Batch 41	1	9	231 µm		
Experiment	Batch 41	1	10	176 µm		
Experiment	Batch 41	2	1	278 µm	168 µm	43.1 µm
Experiment	Batch 41	2	2	166 µm		
Experiment	Batch 41	2	3	158 µm		
Experiment	Batch 41	2	4	116 µm		
Experiment	Batch 41	2	5	160 µm		
Experiment	Batch 41	2	6	188 µm		
Experiment	Batch 41	2	7	147 µm		
Experiment	Batch 41	2	8	158 µm		
Experiment	Batch 41	2	9	167 µm		
Experiment	Batch 41	2	10	141 µm		
Experiment	Batch 42	1	1	130 µm	119 µm	19.2 µm
Experiment	Batch 42	1	2	152 µm		
Experiment	Batch 42	1	3	146 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
Experiment	Batch 42	1	4	115 µm		
Experiment	Batch 42	1	5	112 µm		
Experiment	Batch 42	1	6	111 µm		
Experiment	Batch 42	1	7	115 µm		
Experiment	Batch 42	1	8	88.8 µm		
Experiment	Batch 42	1	9	102 µm		
Experiment	Batch 42	1	10	119 µm		
Experiment	Batch 42	2	1	121 µm	116 µm	13.9 µm
Experiment	Batch 42	2	2	113 µm		
Experiment	Batch 42	2	3	126 µm		
Experiment	Batch 42	2	4	133 µm		
Experiment	Batch 42	2	5	90.2 µm		
Experiment	Batch 42	2	6	108 µm		
Experiment	Batch 42	2	7	132 µm		
Experiment	Batch 42	2	8	117 µm		
Experiment	Batch 42	2	9	98.3 µm		
Experiment	Batch 42	2	10	119 µm		
Experiment	Batch 43	1	1	126 µm	145 µm	26.3 µm
Experiment	Batch 43	1	2	169 µm		
Experiment	Batch 43	1	3	153 µm		
Experiment	Batch 43	1	4	152 µm		
Experiment	Batch 43	1	5	126 µm		
Experiment	Batch 43	1	6	153 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
Experiment	Batch 43	1	7	202 µm		
Experiment	Batch 43	1	8	112 µm		
Experiment	Batch 43	1	9	128 µm		
Experiment	Batch 43	1	10	135 µm		
Experiment	Batch 43	2	1	184 µm	141 µm	41.8 µm
Experiment	Batch 43	2	2	230 µm		
Experiment	Batch 43	2	3	162 µm		
Experiment	Batch 43	2	4	128 µm		
Experiment	Batch 43	2	5	147 µm		
Experiment	Batch 43	2	6	112 µm		
Experiment	Batch 43	2	7	86.3 µm		
Experiment	Batch 43	2	8	111 µm		
Experiment	Batch 43	2	9	130 µm		
Experiment	Batch 43	2	10	117 µm		
Experiment	Batch 44	1	1	365 µm	214 µm	98.7 µm
Experiment	Batch 44	1	2	340 µm		
Experiment	Batch 44	1	3	352 µm		
Experiment	Batch 44	1	4	140 µm		
Experiment	Batch 44	1	5	213 µm		
Experiment	Batch 44	1	6	150 µm		
Experiment	Batch 44	1	7	154 µm		
Experiment	Batch 44	1	8	157 µm		
Experiment	Batch 44	1	9	154 µm		

PERIOD	BEAD #	PROFILE	LINE NUMBER	LENGTH IN MICRONS	MEAN	STD. DEV
Experiment	Batch 44	1	10	114 µm		
Experiment	Batch 44	2	1	366 µm	77.9 µm	119 µm
Experiment	Batch 44	2	2	141 µm		
Experiment	Batch 44	2	3	168 µm		
Experiment	Batch 44	2	4	96.1 µm		
Experiment	Batch 44	2	5	89.9 µm		
Experiment	Batch 44	2	6	99.4 µm		
Experiment	Batch 44	2	7	57.7 µm		
Experiment	Batch 44	2	8	68.1 µm		
Experiment	Batch 44	2	9	76.9 µm		
Experiment	Batch 44	2	10	71.6 µm		

Glossary

Alkali

Soluble salts obtained from plant ash, natron or a combination of the two.

Application Glaze

The faience core is formed then the glaze is applied by either dipping or brushing.

Cementation

Self-glazing technique, which consists of the faience core being covered in glazing powder, which sinks into the core.

Corning Glass Standards

Internationally recognised values for industrial glass specimens that have been tested significantly and have been fully certified.

Efflorescence

Self-glazing method where the core material is mixed with water soluble salts, which when dry rise to the surface and evaporate causing a glaze to form.

Faience

Glazed, non-clay, ceramic consisting of predominantly silica core.

Interstitial glass

Glassy vitreous material viewed within the core of the faience material.

Munsell Colour System

A standardised colour system, which specifies colour based on hue, value (lightness) and colour purity.

Sintered

When the faience object is heated sufficiently so that some of it melts or reacts to form a liquid, which when cooled cements and fuses the silica grains together.

Stoichiometry

The calculation of quantitative relationships of the reactions and products in chemical reactions.

Thixotropic

A substance which is thick like a solid, but can flow like a liquid under certain conditions.

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